AGRICULTURAL AIR TO AIR HEAT EXCHANGER

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MANITOBA/CANADA CONSERVATION AND RENEWABLE ENERGY DEMONSTRATION AGREEMENT

The availability of secure and affordable energy supplies is a subject of national concern. It is an accepted fact that our primary energy sources — oil and natural gas — are becoming less accessible and more costly. However, Canada is well-endowed with renewable and alternative resources that can provide a bridge into the future.

To this end, the governments of Manitoba and Canada entered into a Conservation and Renewable Energy Demonstration Agreement which was signed May 9, 1980 and terminated March 31, 1984. The Agreement was dedicated to the development and demonstration of conservation and renewable energy technologies. Equally cost-shared by the provincial and federal governments, the program had a total budget of $18-million.

The objectives of CREDA are:

- To develop and demonstrate promising new technologies, which, when widely adopted, will exploit renewable resources, conserve energy and/or use energy more efficiently.
- To develop broad public awareness of the potential of renewable energy and conservation technology.
- To provide opportunities for the commercial application of the technologies within Manitoba.
- To create economic spin-off benefits for manufacturing, industry and commerce.
- To create employment in new or existing energy-related industries.

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TABLE OF CONTENTS

SECTION		PAGE
	DISCLAIMER	i
	TABLE OF CONTENTS	ii
1.0	EXECUTIVE SUMMARY	iii
2.0	INTRODUCTION	1
3.0	EXPERIMENTAL AND CALCULATIONS	2
	3.1 Klippenstein Barn	2
	3.2 Riese Barn	11
	3.3 Kehler Barn	19
	3.4 Rempel Barn	27
4.0	DISCUSSION	33
5.0	CONCLUSIONS	33
6.0	RECOMMENDATIONS	33
APPENDIX I	Manitoba Agriculture Report on 1984 Field Testing of Robbco Heat Exhanger	34
APPENDIX II	Determination of Energy Savings Effected by Robbco Model A1 Heat Exchanger in the Winnipeg Area	50
APPENDIX III	Robbco Brochure	52

FIGURES:

1.	Klippenstein Barn	4
2.	Riese Barn	12
3.	Kehler Barn	20
4.	Rempel Barn	28

TABLES:

1.	Summary of Operating Conditions - Klippenstein	6
2.	Temperature Readings - Klippenstein	7
3.	Summary of Operating Conditions - Riese	17
4.	Summary of Operating Conditions - Kehler	23
5.	Summary of Operating Conditions - Kehler	24
6.	Summary of Operating Conditions - Rempel	30
7.	Summary of Operating Conditions - Rempel	31

1.0 EXECUTIVE SUMMARY

Canada and Manitoba, under the Federal/Provincial Conservation and Renewable Energy Demonstration Agreement (CREDA) funded this project in which four production prototypes of an agricultural heat recovery ventilator (air to air heat exchanger) were constructed and installed in four different hog barns.

The purpose of this project was to demonstrate that heat recovery ventilators (HRV's) can be applied to multi-room farrowing-nursery operations to reduce the amount of electrical energy required for heating the fresh air supply to the rooms.

HRV's were monitored in four different applications:

- Heat recovery from the exhaust air from finishing barn to preheat air to grower barn (Rempel farm)

- Heat recovery from the exhaust air of a dry sow housing facility used to preheat make-up air for the same barn (Riese farm)

- Exhaust air from dry sow and nursery areas to preheat air for farrowing and nursery areas (Kehler farm)

- Exhaust air from dry sow, farrowing and nursery areas to preheat air for farrowing and nursery areas (Klippenstein farm).

Over the monitoring period, the units operated in an effective manner without incidence of icing or fouling. Ambient temperatures varied from 20°C to -27°C and no routine maintenance or servicing were required. All of the farmers expressed satisfaction with the operation of the heat recovery device.

Based on tests carried out by Manitoba Agriculture, the enthalpy efficiency ranged from 20% to 35% depending on the installation and operating conditions. The sensible effectiveness, as determined by the Prairie Agricultural Machinery Institute (PAMI) heat recovery ratio, ranged from 32% to 64% over all test conditions. This is comparable to other commercial units.

The simple payback period for these retrofit applications varied from 2.3 to 2.8 years for total investments ranging between $2,680 to $3,645.

On new installations the unit would eliminate the need for approximately 20 kW of heat. Allowing that the costs of installing this capacity of electrical heating could be avoided by the use of the HRV, the payback on the device would be less than one year for new applications.

1.0 RÉSUMÉ ADMINISTRATIF

Dans le cadre de ce projet, qui a été financé en vertu des Accords de démonstration des économies d'énergie et des énergies renouvelables (A.D.E.E.E.R.), quatre prototypes d'un ventilateur agricole de récupération de la chaleur (échangeur de chaleur air-air) ont été fabriqués et installés dans quatre différentes porcheries.

Ce projet visant à démontrer que les ventilateurs de récupération de la chaleur peuvent être utilisés dans des opérations de maternité à plusieurs pièces pour réduire la consommation de l'énergie électrique qu'il faut pour réchauffer l'air neuf apporté aux pièces de l'établissement.

Les ventilateurs de récupération de la chaleur ont été contrôlés dans quatre situations différentes :

- La récupération de la chaleur provenant de l'air d'évacuation de la porcherie d'engraissement pour réchauffer d'avance l'air fourni à la porcherie de postsevrage (ferme Rempel).

- La récupération de la chaleur provenant de l'air d'évacuation du bâtiment de gestation pour réchauffer d'avance l'air de compensation destiné au même bâtiment (ferme Riese).

- L'air d'évacuation des locaux de gestation et de maternité pour réchauffer d'avance l'air destiné aux locaux de maternité (ferme Kehler).

- L'air d'évacuation des locaux de gestation et de maternité pour réchauffer d'avance l'air destiné aux locaux de maternité (ferme Klippenstein).

Pendant la période de contrôle, les appareils ont fonctionné de façon efficace sans qu'il y ait de givrage ou d'encrassement. Les températures de l'air ambiant variaient entre 20°C et -27°C, et il n'a pas été nécessaire de faire l'entretien ou la révision de façon régulière. Tous les fermiers étaients satisfaits du fonctionnement de l'appareil de récupération de chaleur.

Selon des épreuves effectuées par Agriculture Manitoba, l'efficacité des appareils, d'après l'enthalpie, allait de 20 % à 35 %, selon les conditions d'installation et de fonctionnement. L'efficacité perceptible, suivant le rapport de récupération de chaleur indiqué dans les normes établies par le Prairie Agricultural Machinery Institute (PAMI), variait entre 32 % et 64 %, pour tous les essais. Cette efficacité se compare à celle d'autres appareils commerciaux.

La période de récupération simple des frais pour ces appareils varie entre 2,3 et 2,8 années. Les coûts totaux s'élèvent entre 2 680 $ et 3 645 $.

Si cet appareil était installé au cours de la construction du bâtiment, il réduirait le montant de chaleur nécessaire d'environ 20 kW. Compte tenu du fait que le coût d'installation d'un appareil de chauffage électrique de cette puissance pourrait être éliminé en utilisant le ventilateur de récupération de chaleur, la période de récupération simple des dépenses équivaudrait à moins d'un an.

2.0 INTRODUCTION

Ventilation in animal barns is required to control the relative humidity and thus prevent damage to the building and eliminate adverse effects on the health of the animals.

These installations demonstrate the feasibility of heat recovery for multi-room hog barns in which exhaust air is diverted into a central heat exchanger rather than being dumped directly outdoors. Heat is transferred to incoming fresh air which is delivered to the central air supply plenum, i.e. preheat hall, of this operation. Substantial capital costs in new buildings for electrical heating equipment are saved, corresponding to the peak heating capacity of the heat exchanger, ie. 20 kWs.

The potential for energy savings in hog barns is greater than in other barns because of the elevated room temperatures required for rearing the young pigs. Monitoring by the owners, Manitoba Agriculture and Robbco has produced encouraging data on the performance of the Robbco Model A1 heat exchanger at these hog barns, details of which form a part of this report.

3.0 EXPERIMENTAL AND CALCULATIONS

3.1 E.D. KLIPPENSTEIN BARNS

3.1.1 Ventilation System

The HRV consists of a number of rows of thin walled 2 mil polyethylene tubing attached at each end to a header. The heat from the exhaust air is transferred to the incoming fresh air and at the same time the moisture in the exhaust condenses and flows down the tube, thereby scrubbing the surface. To prevent ice build-up the incoming air is stopped on a regular basis and the warm exhaust air melts any ice on the tubes which then draws away removing any dirt, etc.

The attached sketch entitled "E.D. Klippenstein Barn" (Figure 1) shows a schematic of the installation. This barn contains a farrowing-nursery, breeding and gestation (dry sow) operation including 140 sows. There are 30 farrowing crates in total in the farrowing area.

Floors in the farrowing and weanling areas are 100% slotted while the dry sow area floors are 30% slotted and watering is totally by nipples.

Exhaust ducts on both the north and south walls of the farrowing-nursery section are cross connected and tied to exhaust fans which drive exhaust air into the HRV. In addition, a 6" square inlet in the dry sow area allows some of the exhaust from this area to be delivered into the HRV. Exhaust fans at the opposite ends of the long ducts are used to exhaust air directly outdoors during summer months. Further ventilation (without heat recovery) is provided by thermostatically operated exhaust fans in each room which discharges directly outdoors to ensure that proper temperatures are sustained.

3.1.2 Animal Heat Load

The amount of heated exhaust that passes into the HRV is difficult to determine in a farrowing-nursery barn. Animal densities in such an operation are lower than those of finishing barns. Additional heating equipment is often used in the rooms due to the required higher temperatures for young pigs and current design includes thermostatically actuated wall exhaust fans so that only some of the exhaust air passes through the exchanger.

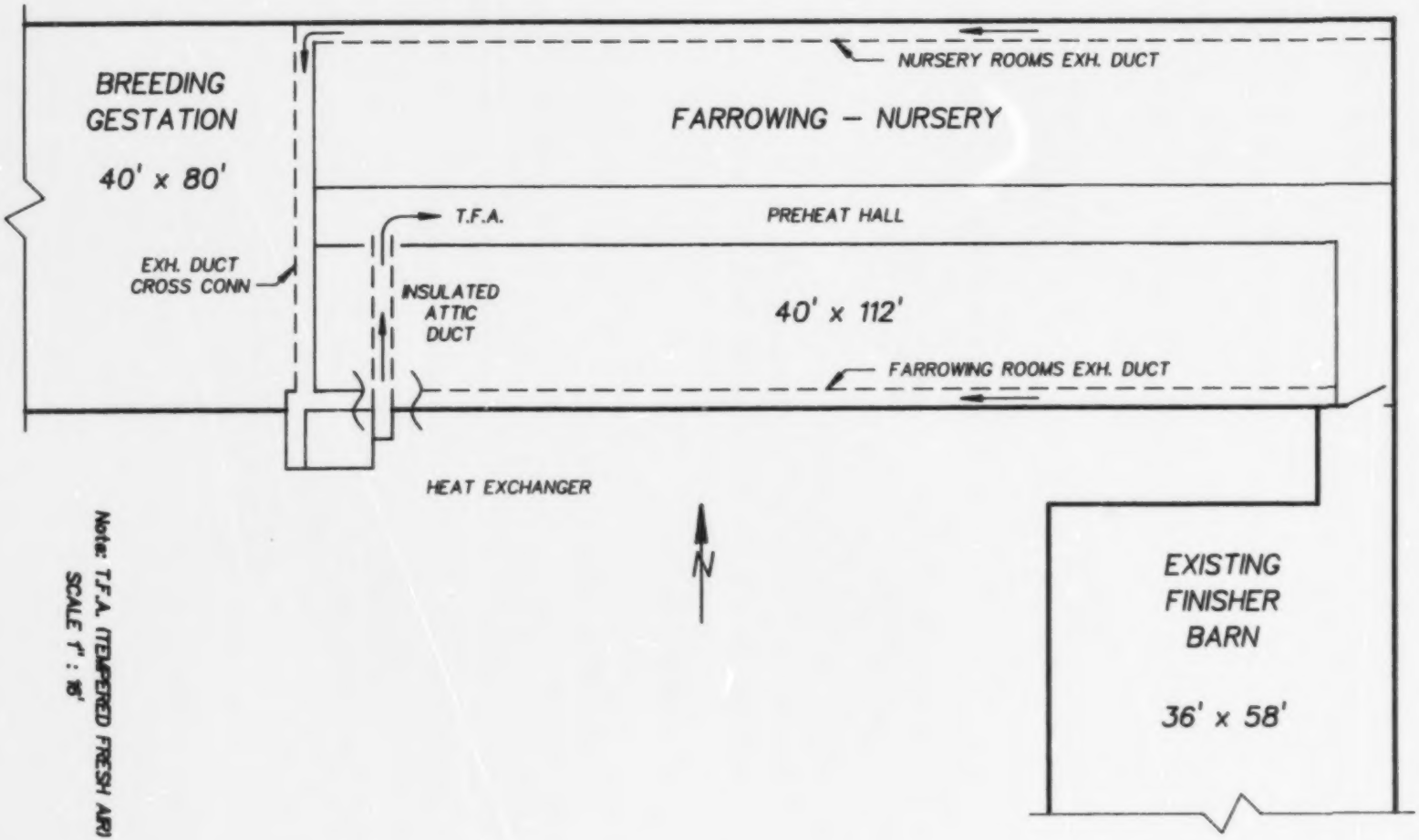
3.1.3 Description of Barn

Rectangular with the farrowing-nursery operation at the east end and the breeding-gestation at the west end. The farrowing-nursery area is 40' x 112' = 4,480 square feet while the breeding-gestation section is 40' x 80' = 3,200 square feet totalling 7,680 square feet. This structure was built in 1983. An existing finisher barn is linked through a normally closed door at the south east corner.

Walls (R-20) - 3/8" plywood sheathing on 2" x 6" studs at 24" o.c. with 6" friction fit glass fibre between, polyethylene vapour barrier, 3/8" plywood interior sheating.

Ceiling (R-20) - Plywood over polyethylene vapour barrier attached to underside of lower chord of roof truss, roof trusses at 24" o.c. with 6" friction fit fibreglass between.

Figure 1 –KLIPPENSTEIN BARN



Note: T.F.A. (TEMPERED FRESH AIR)
SCALE 1" : 16'

Within the roofspace, there is a plywood duct insulated with 4" glass fibre which conducts tempered fresh air from the heat exchanger to the preheat hall of the farrowing-nursery section.

There are no windows in the building. There are two - 5 kW electric heaters each in the preheat hall and breeding-gestation area.

3.1.4 HRV Installation

A Robbco Model A1 heat exchanger (HRV) has been installed on the south side of the building at approximately 80 feet from the west wall at a point where it can draw exhaust air from both barn sections with a minimum of ducting. The exhaust fan (14") (480 L/S) draws air from each room according to the adjustment of dampers at the duct openings in the rooms and discharges the air to atmosphere after passing through the heat transfer tubes.

Because the exchanger was not installed at a gable end wall, a dormer was required at a cost of $500. As well, an insulated duct was installed in the attic at a further cost of $300 to deliver tempered fresh air from the exchanger into the preheat hall of the farrowing-nursery section.

3.1.5 Test Results

A number of temperature and humidity readings were taken from time to time by Robbco as listed in Tables 1 and 2.

Proper barn and heat exchanger conditions were not realized until the end of January 1984 due to the scheduling of the sows. Difficulties with exhaust air distribution were corrected with modifications of the air baffles in the exhaust section as was done with all

units. No cleaning of the exchanger was required as was the case with all other units. This unit drained outdoors initially but the operator became concerned about the amount of daily labour required for ice removal and the assembly was then drained to indoors.

TABLE 1

SUMMARY OF OPERATING VARIABLES

KLIPPENSTEIN BARN

Temperature - (^{o}C)

Date	Outdoor	Preheat Hall	Tempered* Fresh Air Duct Inlet	Exhaust Fan	Roofspace	Relative ** Humidity Preheat Hall
1984						
Jan.28	-14^{o}	+12^{o}	+ 4^{o}	17^{o}	--	--
Feb.11	- 2^{o}	+11^{o}	+10^{o}	18^{o}	+ 3^{o}	78
Mar. 8	-16^{o}	+ 5^{o}	+ 1^{o}	18^{o}	-16^{o}	56

* This temperature is 1^{o}C lower than what is obtained from the heat exchanger due to heat loss as air travels along the length of the duct into the preheat hall.

** The relative humidity of the preheat hall is not an indicator of room conditions and is considerably lower because it is air that has been supplied from the roofspace. The high reading for February 11, 1984 may have been due to washdown of facilities or introduction of moist air shortly before this check from the adjoining existing barn.

TABLE 2

TEMPERATURE READINGS - KLIPPENSTEIN BARN

Temperature ^{o}C

Date	Time	Therm. "A"	Therm. "B"
January 26	9:00 a.m.	9	4
January 30	9:45 a.m.	8.5	1.5
February 2	11:35 a.m.	12	7.5
February 9	10:00 a.m.	8	3
February 14	8:15 a.m.	9.5	8.5
February 16	9:30 a.m.	10.2	10
February 21	11:00 a.m.	12	12.5
February 23	11:30 a.m.	9	8.5
February 23	9:15 p.m.	6.5	4.5
March 1	9:15 a.m.	5.2	0
March 8	10:20 a.m.	6.5	3.5
March 15	10:45 a.m.	6	1
March 22	10:45 a.m.	10	11
March 30	12:00 a.m.	13	17

Thermometer "A" was mounted on one of the walls of the preheat hall approximately at the mid-point of the farrowing-nursery area.

Thermometer "B" was mounted immediately adjacent to the inlet into the preheat hall from the attic duct.

3.1.5a Determination of Energy Savings Effected by Robbco Model A1 Heat Exchanger in the Winnipeg Area:

Method - The peak capacity of 20 kW, as determined by test conducted by Agriculture Manitoba, is prorated according to the normal winter mean temperature for each month. This prorated capacity is multiplied by the operating time of the HRV (number of days in a month times 24 hours) to obtain the number of kW.hs of heat transferred. This calculation is totalled for the period of November 1 to April 15 inclusive. (One operator ran his exchanger for the month of May of 1984 during the nights to save electrical heating. The month of May in 1984 was extraordinarily cool).

The average temperature of the exhaust air was 17°C from the nursery rooms along with a small amount from the dry sow area.

The peak capacity of 20 kW, as determined by M.D.A., is based on a temperature difference of 50°C between indoors and outdoors. When the difference is less than 50°C, the "Factor" below is less than 1.0.

Month	Temp.*	Ins. to Outs. Temp. Diff.	Factor	Factor x 20=kW. Avg. H.X. Cap.	kW.h** Saved
Jan.	-33°	50°	10	20	$14,880
Feb.	-16°	33°	.66	13.2	8,870
March	- 8°	25°	.50	10	7,440
Apr.(50%)	+ 3°	14°	.28	5.6	2,016
Nov.	- 4°	21°	.42	8.4	6,048
Dec.	-14°	31°	.62	12.4	9,226
				Total	$48,480

* Based on Winnipeg area.
** = kW.h average heat exchanger capacity x 24 hours x days in month
Annual saving @ 3¢ per kW.h = $1,454.

3.1.6 Economic Analysis

The cost of this installation is broken down as follows:

Robbco Heat Exchanger		$ 2,500
Shipping		50
Installation		220
Wiring		75
	Total	$ 2,845
+ Dormer		500
+ Insulated duct		300
	Total	$ 3,645

The energy recovered during a normal Winnipeg area winter is estimated to be 48,480 kW.h with an average temperature of the exhaust air of +17°C which, at 3¢ per kW.h, totals $1,454. This calculation is contained in Appendix "II". It does not include electrical consumption of the heat exchanger fans which is estimated to cost $100 annually. This reduces the saving to $1,354.

For this net saving, the simple payback period for the installed heat exchanger is $2,845 - $1,354 = 2.1 years. When the dormer and the insulated duct are included with the exchanger, the simple payback period increases to $3,645 - $1,354 = 2.7 years.

However, when one considers the capital savings achievable at the planning stage of a new barn, as occurred in this case, the payback periods are much improved. The capital cost savings are:

Four - 5 kW heaters @ $410 each	$ 1,640
Reduction of electrical service capacity by 20 kW., labour and material	360
Mounting and connection of 4 - 5 kW. heaters omitted by installation of Robbco A1 heat exchanger (material = $70.00 x 4, labour = 4 hours x 4 @ $25.00)	680
Total	$ 2,680

When these savings are considered, the simple payback period for the installed exchanger is ($2,845 - $2,680)/$1,354 = 0.12 years

When the dormer and the insulated ductwork are included with the exchanger, the simple payback period is ($3,645 - $2,680)/$1,354 = .71 year.

3.2 RIESE - WESTPHALIA FARM

3.2.1 Livestock Operation

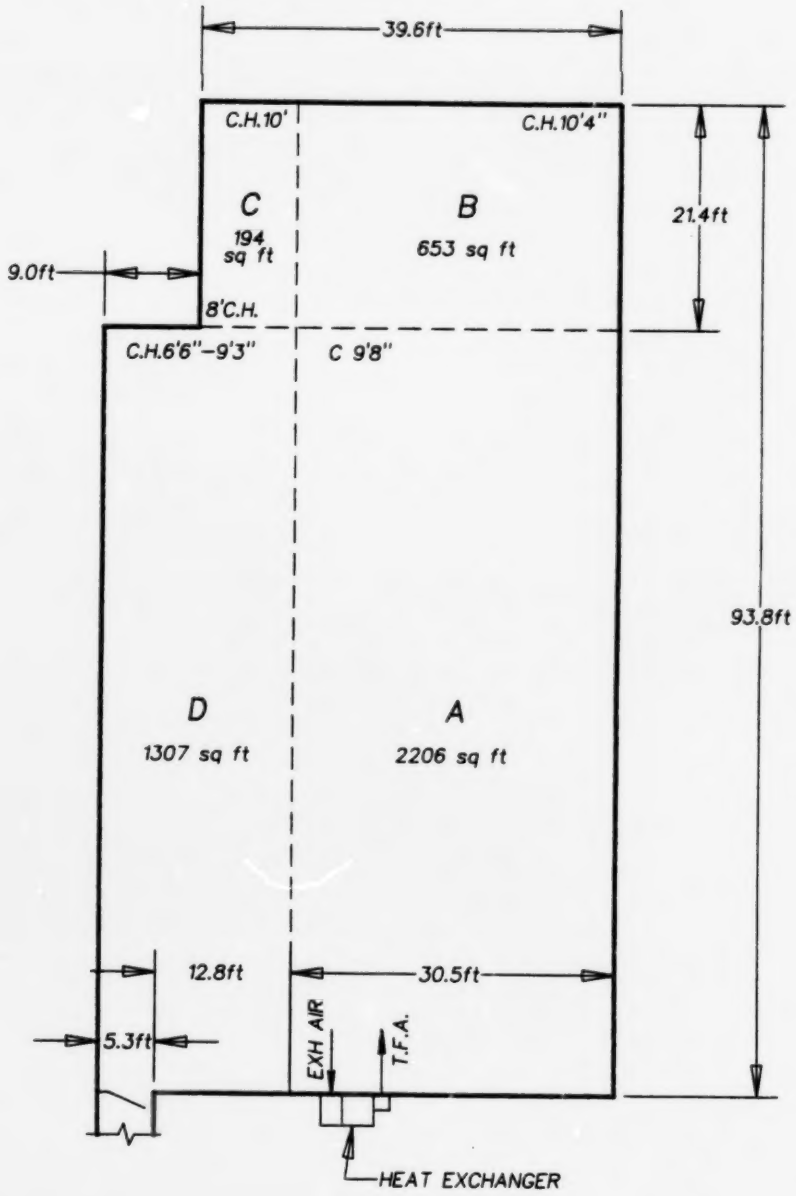
The barn, shown on the sketch titled "Westphalia Farms Ltd." (Figure 2), contains a mixed operation of dry sows and finisher pigs. The sows, 50 in number, are in the section of the barn labelled "A" while the remainder of pigs, 125 in number, occupy sections B-D inclusive. The sows are held by collars chained to the floor in two rows with a water filled gutter between them. In the finisher area, Section "D", there is a similar gutter running the length of this section along the dividing wall between it and Section "A". These gutters present approximately 430 square feet of water surface in the barn. Feed is distributed throughout by cart and drinking water is by a pressure system into continuous troughs to the sows. The remaining pigs are watered from nipples on the pressure system.

3.2.2. Animal Heat Load

The population in this barn was on the low side with a maximum of 40,000 lbs. of animals and a minimum of 37,000 lbs. This amounts to a maximum animal heat load of 160,000 - 4,354 = 36.75 BTU/sq.ft. This is a small load compared to finishing operations at 57 BTU/sq.ft.

3.2.3. Description of Barn

Multi-section with total area of 4,354 square feet (Figure 2).



Note: C.H. (CEILING HEIGHT)
T.F.A. (TEMPERED FRESH AIR)
SCALE 1" : 16'

Figure 2 –RIESE BARN

Section "A"

Walls = 43% of total building walls, R4 insulation value, 9' 8" high.

South: Interior finish of nominal 1" tongue and groove boards over 5/8" thick insulboard on 2" x 8" studs at 24° o.c. finished on the exterior by shiplap boards.
East: Same as South except exterior finish is 3/8" plywood.

Ceiling = 51% of total ceiling area, R16 insulation value. 1/2" plywood, polyethylene vapour retarder, 2" x 8" wooden joists with spaces filled with 8" wood shavings.

Section "B"

Walls = 23% of total walls, R12 insulation value, 10' 4" high.
1/2" plywood on 2" x 4" studs at 24" o.c., 3 1/2" fiberglass between studs and 3/8" plywood exterior finish.

Ceiling = 15% of total ceiling area, R16 insulation value. 1/2" plywood, polyethylene vapour retardant, attached to 2" x 4" lower chord of prefabricated roof trusses, 8" wood shavings insulation.

Section "C"
Walls = 11% of total building walls, R12 insulation value, 8' 10" high.
1/2" plywood on 2" x 4" studs at 24" o.c., 3 1/2" fiberglass between studs finished on the exterior with 3/8" plywood.

Ceiling = 4% of ceiling area, R12 insulation.
1/2" plywood on 2" x 4" rafters with 3 1/2" fibreglass between rafters.

Section "D"

Walls = 23% of total wall area, R20 insulation value, 6' 6" - 9' 3" high.
Nominal 1" boards on 2" x 8" studs at 24" o.c. and believed to be 6" fibreglass between studs finished on the exterior with 3/8" plywood.

Ceiling = 30% of total ceiling area, R12 insulation value.
1/2" plywood attached to 2" x 6" rafters at 24" o.c. with 4" fibreglass between finished on the exterior with nominal 1" boards and sheet metal over.
Windows in South and West walls are single glazed.

Concrete floors throughout with continuous watering troughs for the sows and nipple waterers fed by pressure system for all other pigs. Thirty inch wide water filled gutters are located in Sections "A" and "D".

There is one 5 kW. heater located in the finisher area in Section "D" which was not operated during this past winter.

3.2.4. Heat Exchanger Installation

A Robbco Model A1 heat exchanger was installed on the South wall of Section "A" of the barn. The tempered fresh air inlet and the exhaust air outlet are both located below the ceiling while a fresh air inlet is located in the attic space. Two circulating fans were installed within 5' and 8' from the tempered fresh air inlet and are fitted with perforated polyethylene ducting. These units mix the tempered fresh air with barn air and deliver it into all sections of the barn. The tempered fresh air inlet is fitted with a diverter which directs this clean air onto the ceiling for mixing without impinging directly onto the animals.

3.2.5 Test Results

Shortly after start up of the heat exchanger on December 12, 1983, walls and ceilings dried off with the tempered fresh air supplied by the exchanger. The walls at the entrance door at the South end of Section "D" were wet and accumulated some ice as cold air entered through substantial openings around this door, chilling the adjacent surfaces.

Shortly after start up, ice formation within the unit soon indicated poor exhaust air distribution. The initial duct baffle was removed and replaced with a modified design which provided good air distribution and much improved efficiency of the unit. The outside drain line froze causing the lower cap to accumulate approximately 23 litres of water by the time this problem was detected. This drain was thawed and routed to the inside of the barn and insulated. Because the volume of water discharged by the exchanger is sufficient to

require daily removal of ice in the case of outside discharge, the drain should be routed indoors and insulated to avoid this labour.

A 20" wall exhaust fan controlled by a thermostat developed sufficiently high negative pressure in the barn to upset operation of the heat exchanger. An automatic fresh air inlet was installed in the ceiling which limits negative pressures to a level which will not adversely affect the exchanger. Before its installation, conditions were such as to prevent proper defrost of the exchanger as well as reducing the amount of air exhausted by the unit. This exchanger operated for the entire heating season without requiring any cleaning by the owner. The design is such that accumulations are removed by condensation and ice and discharged to drain.

A number of temperature and humidity readings were taken periodically by Robbco Ltd. as listed in Table 3:

TABLE 3

SUMMARY OF OPERATING CONDITIONS

RIESE FARM

Date	Temperatures (°C) Outdoor	Barn Interior	At Exhaust Fan	Tempered Fresh Air Inlet	Roofspace	Rel.** Humidity Inside Barn %
01/07/84	-13	--	17	7	--	--
01/14/84	-25	13	11	-2	--	70
01/29/84	-14	17	16	6	-10	84*
02/11/84	- 2	19	17	11	2	77
02/26/84	- 3	16	13	7	1	75

* Extraordinary sources of humidity exist as follows. Heat exchanger condensate is splashed onto floor rather than being piped to drain. Ice accumulations on single glazed windows had melted off at the time of this check. Also, outside wall sheathing exposed by large holes in interior wall sheathing has melted off ice accumulations that occurred during colder weather.

** Because the 20" wall exhaust fan was drawing continuously from the roofspace through the automatic air inlet, the exchanger exhaust fan was mixing roofspace air with barn air resulting in an exchanger exhaust temperature of 13°C, 3° below barn temperature.

3.2.6 Economic Analysis

The cost of this installation is broken down as follows:

Robbco Heat Exchanger	$2,500
Shipping	50
Installation	350
Electrical Connection	120
Total	$3,020

The energy recovered during a normal Winnipeg area winter is estimated to be 41,524 kW.hs with an average interior barn temperature of 16°C which, at 3¢ per kW.h, totals $1,407. This calculation is contained in Appendix "II". This figure reduces by $100 for energy consumption by the exchanger's two fans to $1,307.

On this basis, the simple payback period is $3,020 - $1,307 = 2.3 years. Though the annual energy consumption by the exchanger fans is included, one could argue that the existing 20" wall fan does not use as much energy as it would if the exchanger was not in operation so that its savings should be applied to reduce the assessable energy consumption of the exchanger fans.

3.3 A.D. KEHLER BARN

3.3.1 Livestock Operation

The attached sketch titled "A.D. Kehler Barn" (Figure 3) shows a farrowing-nursery, breeding and gestation operation including 180 sows. There are 40 farrowing crates in total in the farrowing area.

Floors in the farrowing and weanling areas are 100% slotted while the breeding-gestation area floors are 30% slotted and watering is entirely by nipples.

Both the East and West walls of the farrowing-nursery section are fitted with exhaust ducts that are equipped with exhaust fans at the South end. The ductwork along the East wall which serves the nursery areas is tied to the Robbco heat exchanger. As well, a variable opening into this duct permits exhaust from the breeding-gestation area into the heat exchanger.

The West duct serves the farrowing rooms and is exhausted directly to outdoors.

3.3.2 Animal Heat Load

The amount of this load destined for the heat exchanger is difficult to determine in a farrowing-nursery barn. Animal densities in such an operation are lower than those of finishing barns. Additional heating equipment is often used in the rooms due to the higher temperatures required for young pigs and current design includes thermostatically controlled exhaust fans so that a fraction of the animal heat load in a given area is exhausted by the heat exchanger.

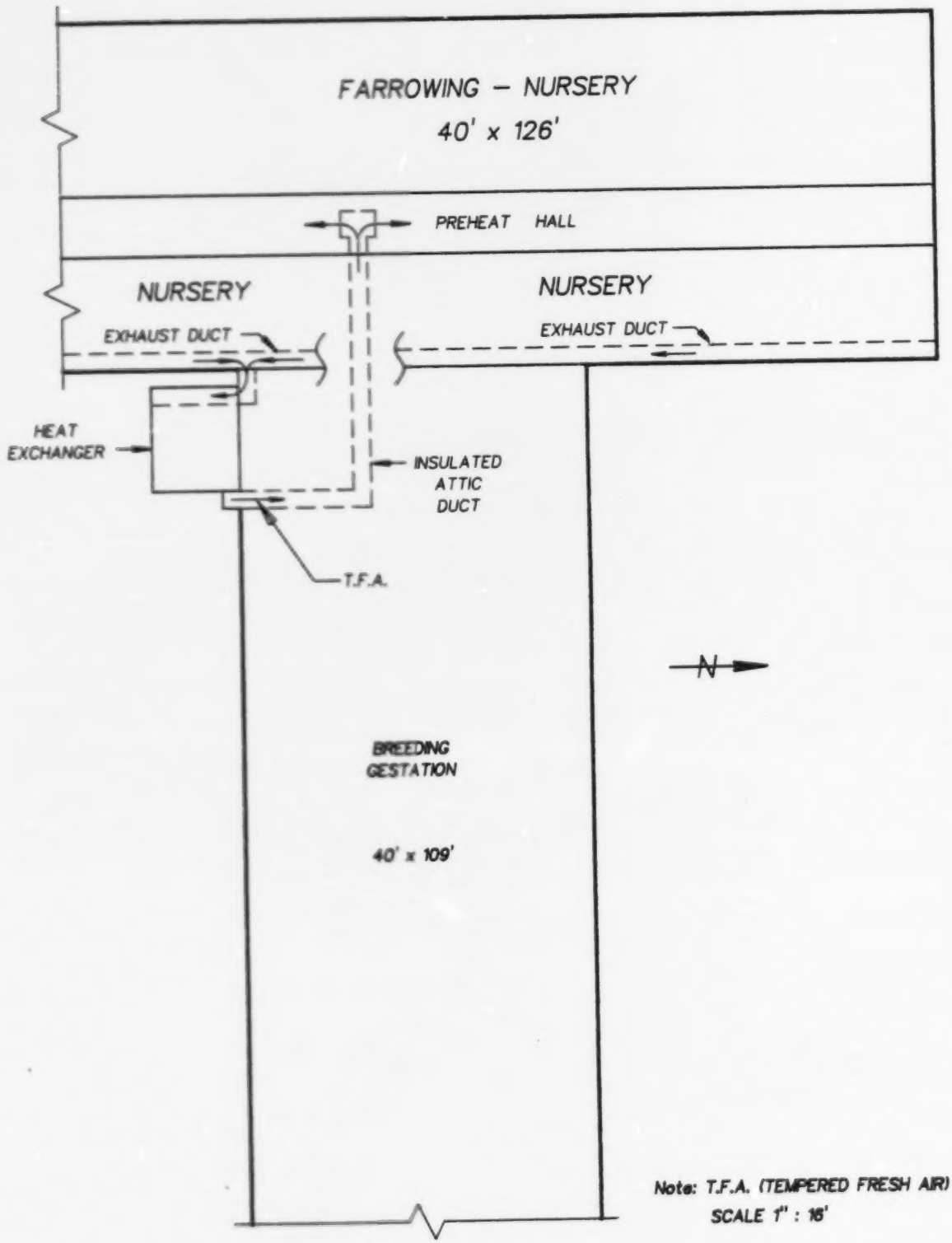


Figure 3 – KEHLER BARN

3.3.3. Description of Barn

"T" shaped with the farrowing-nursery section in the "horizontal" portion of the tee and the breeding-gestation operation (dry sow) in the "vertical" of the tee. This building was constructed in 1983.

"Horizontal" section	40' x 126' =	5,040 sq.ft.
"Vertical" section	40' x 109' =	4,360 sq.ft.
	Total	9,400 sq.ft.

Walls: (8 1/2' high, R=20 construction)
Sheet metal cladding mounted on horizontal 1" x 4" strapping on 2" x 6" studs at 16" o.c. with 6' friction fit fibreglass insulation, vapour barrier with interior 3/8" plywood sheathing.

Ceiling: (R=20)
Plywood over polyethylene vapour barrier attached to lower chord of roof trusses, 10" - 12" of shavings insulation.

Floor:
Concrete, 30% slotted in dry sow area and 100% slotted in farrowing-nursery rooms.

Within the roofspace, there is a plywood duct insulated with 4" of fibreglass which conducts tempered fresh air from the heat exchanger to the preheat hall in the 40' x 126' section.

There are no windows in the building except for the office. There are 2 - 5 kW. heaters in the preheat hall along with 2 - 5 kW. heaters in the dry sow area.

3.3.4 Heat Exchanger Installation

A Robbco Model A1 heat exchanger has been installed at the junction between the two building sections on the South side of the breeding-gestation operation. The exchanger exhaust duct is coupled to a 14" fan which is mounted inside a building duct. This duct is connected to the exhaust duct along the East wall of the farrowing-nursery operation so as to draw air from 6 nursery rooms. There is an adjustable opening on the ductwork permitting exhaust of air into the heat exchanger from the dry sow area, as well.

The tempered fresh air fan is mounted in the attic space which draws air from the heat exchanger and discharges it into insulated ductwork which, in turn, discharges into the preheat hall of the farrowing-nursery section. As in all other cases, untempered fresh air is drawn into the heat exchanger from the attic so as to benefit from ceiling heat losses into that space.

Defrost:

This unit defrosts by shutting down the tempered fresh air fan for 15 minutes every 3 hours.

3.3.5 Test Results

This exchanger commenced operation February 8, 1984 which was quite late in the heating season due to the scheduling of the sows. Problems of poor air distribution, as experienced in the other units, was avoided by changing the baffling ahead of its operation based on the experience with the other exchangers. No cleaning of the exchanger was required as was the case with all other units. This one drains to outdoors and the owner clears ice away daily to prevent damage to the lower cap.

Operating Variables are listed in Tables 4 and 5.

TABLE 4

SUMMARY OF OPERATING CONDITIONS
KEHLER BARN

Date	Time	Temperature °C Therm. "A"	Therm "B"
1984			
February 13	9:40 a.m.	7	13
February 16	9:39 a.m.	9	11
February 20	10:45 a.m.	4	10
February 23	9:58 a.m.	7	10
February 27	10:55 a.m.	7	10
March 1	11:26 a.m.	6	9
March 5	10:47 a.m.	6	- 2 *
March 8	10:33 a.m.	0	9
March 12	10:18 a.m.	2	6
March 15	9:30 a.m.	-5	6
March 19	9:17 a.m.	7	13
March 22	9:30 a.m.	9	12

The "A" Thermometer is located in the terminal end of the insulated attic duct.

The "B" thermometer is located in the preheat hall at approximately 35' from the North end of the structure.

* The drain in the lower cap froze causing water build up in lower cap. As designed, cap dropped down rather than collapsed releasing exhaust air to atmosphere directly.

Preheat hall temperature recordings by A.D. Kehler

A number of temperature and humidity readings were taken periodically by Robbco as listed below:

TABLE 5

SUMMARY OF OPERATING CONDITIONS - KEHLER FARM

	Temperatures $0^{o}C$					
Date	Outdoor	Preheat Hall	Tempered* Fresh Air Duct Inlet	Exhaust Fan	Roofspace	Rel.** Humidity Preheat Hall %
02/11/84	- 3	+13	+9	+15	+ 1	43
03/05/84	-22	+ 8	-3	+15	-21	--
03/08/84	-16	+12	+1	+17	-13	18

* This temperature is $1^{o}C$ lower than what is obtained from the heat exchanger due to heat loss as air travelled through the duct to the preheat hall.

** Relative humidity in the preheat hall is low because it is outdoor air heated up by the heat exchanger and by two 5 kW. heaters which operated intermittently in the hall. Relative humidity in occupied rooms was considerably higher. Two to three nursery rooms were vacant during the test period as normal operating capacity was not reached during that time.

3.3.6 Economic Analysis

The cost of this installation is broken down as follows:

Robbco Heat Exchanger	$ 2,500
Shipping	50
Installation	220
Electrical Connection	120
	$ 2,890
Dormer	500
Insulated Duct	300
Total	$ 3,690

The energy recovered during a normal Winnipeg area winter is estimated to be 50,074 kW.hs with an average temperature of the exhaust air of +28^{o}C which, at 3¢ per kW.h, totals $1,502. This calculation is contained in Appendix "II". It does not include electrical consumption of the heat exchanger fans which approximates a total of $100. This reduces the saving to $1,402.

For this net saving, the simple payback period for the installed exchanger is $2,890 - $1,402 = 2.1 years.

When the dormer and the insulated ductwork are included with the exchanger the simple payback period increases to $3,690 - $1,402 = 2.6 years.

However, when one considers the capital cost savings achievable at the planning stage of a new barn, as occurred in this case, the payback periods are much improved. The capital cost savings are:

Four - 5 kW heaters at $410 each	$ 1,640
Reduction of electrical service capacity by 20 kW, labour and materials	360
Mounting and connection of 4 - 5 kW heaters omitted by installation of Robbco A1 heat exchanger (material = $70 x 4, labour - 4 hours x 4 at $25.00)	680
Total	$ 2,680

When these substantial savings are obtained, the simple payback period for the installed exchanger is ($2,890 - $2,680)/$1,402 = .15 year.

When the dormer and the insulated ductwork are included with the exchanger, the simple payback period is $3,690 - $2,680)/$1,402 = .72 years.

3.4 REMPEL BARN

3.4.1 Livestock Operation

The attached sketch titled "Rempel Barn" (Figure 4) contains space for slightly more than 600 grower pigs ranging in weight from 40 to 90 lbs. There are livestock feeders supplied by an auger system adjacent to a central corridor. There are overhead hose lines supplied intermittently with water by solenoid valves on a water pressure system. These lines are located above the slotted floor sections along the East and West walls and are for the purpose of training the pigs. This barn is connected by a link, with doors at each end, to the finisher barn and, as the growers mature, they are moved into the finisher area.

3.4.2 Animal Heat Load

There are 18 pens containing 34 pigs each at an average weight of 60 lbs., ie. a total of 36,720 lbs. The area of this barn is 3,633 square feet = 40.4 BTU/sq. ft. For comparative purposes, finisher barns are operated at a load of 57 BTU/sq.ft.

3.4.3 Description of Barn

Rectangular 36' 4" x 100' = 3,633 sq.ft., built in 1969.

Walls: (7' high - R20 construction)
Plywood sheathing on 2" x 6" studs with 6" fiberglass insulation, vapour barrier and internally lined with plywood.

Ceiling: (R=16)
Plywood on lower chords of roof trusses, polyethylene vapour barrier, 8" of shavings insulation. Centre of ceiling is fitted with lengthwise adjustable fresh attic air inlet.

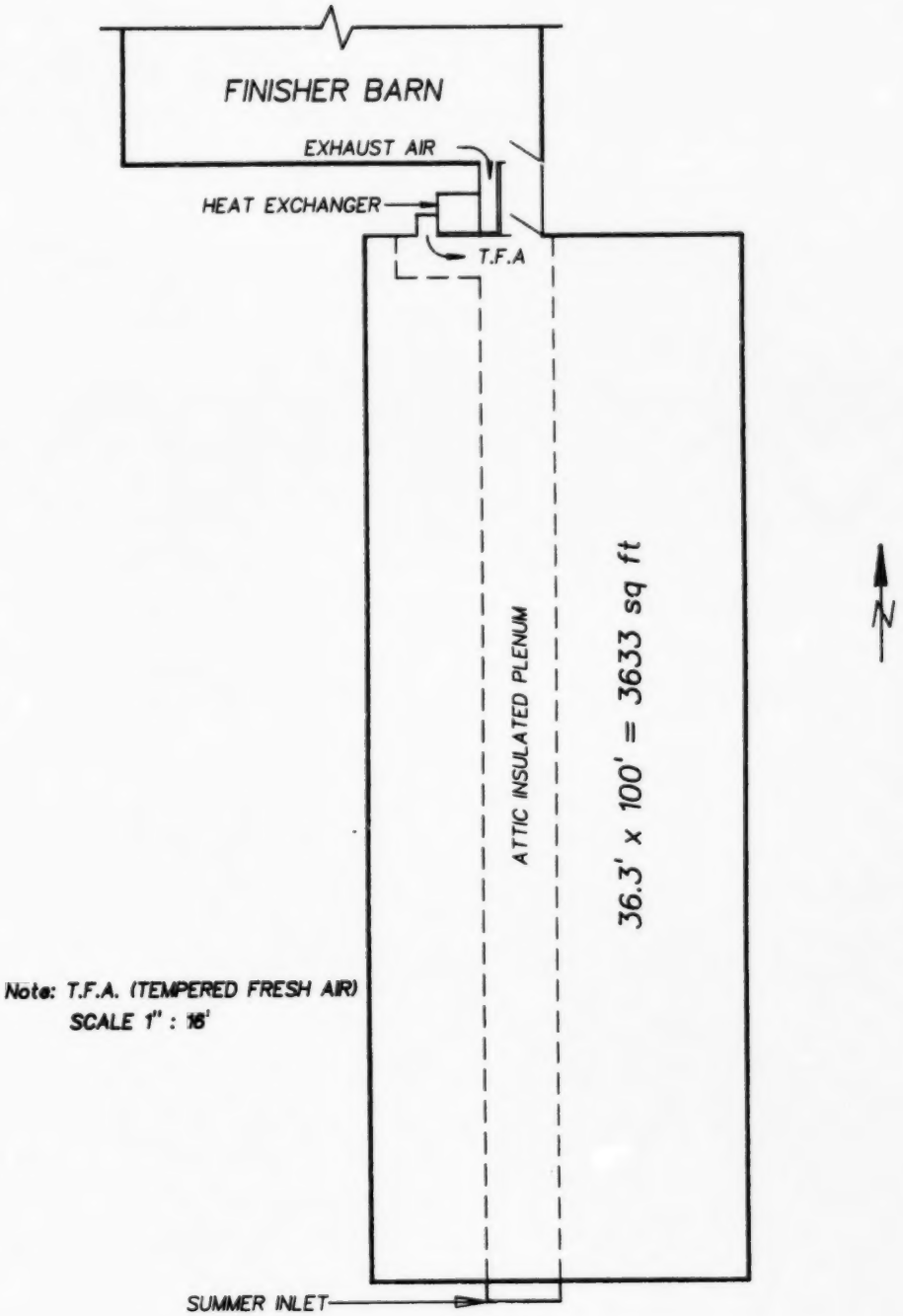


Figure 4 –REMPEL BARN

Floor:
Concrete, solid except slotted over manure pits along East and West walls.

Roofspace:
An R20 insulated plenum is centred on the peak of the roof over the adjustable fresh air inlet and is served in warm weather by a fresh air inlet located in the South wall.

There are no windows in this building.
There are no electric heaters, as well.

3.4.4 Heat Exchanger Installation

A Robbco Model A1 heat exchanger was installed on the North wall of the grower barn adjacent to the connecting link between the grower and finisher barns. The exhaust duct connection was constructed for rear connection and tied to a duct extending Northward into the finisher barn from which exhaust air is obtained. The tempered fresh air is delivered by a vertical duct on the side of the exchanger into the insulated plenum in the roofspace described earlier. Fresh air is drawn from the roofspace through the plenum by an insulated duct into the exchanger.

One 18" fan located in the East wall of the grower barn ran continuously all winter at full speed and, because the exchanger is equipped with only 14" fans, the demand for supply air from the plenum through the adjustable ceiling damper exceeded that supplied by the heat exchanger. As a result, some untempered attic air was continuously drawn into the plenum and mixed with tempered fresh air from the exchanger as it entered the barn.

Defrost: This unit defrosts by shutting down the tempered fresh air fan for 25 minutes every 3 hours.

3.4.5 Test Results

This exchanger commenced operation in the last week of November of 1983.

Although the initial experience was satisfactory after approximately one month of operation the unit had iced up substantially and became quite inefficient. A modified design of exhaust air baffles was installed in the unit with improved results. The exchanger operated for the entire heating season without cleaning by the owner and accumulations on heat transfer surfaces were removed by condensation and ice and discharged through an insulated drain line to one of the manure pits.

Experimental results are shown in Tables 6 and 7.

TABLE 6

SUMMARY OF OPERATING CONDITIONS - REMPEL FARM

	Temperatures $0^{o}C$						Rel.** Humidity Inside Barn %
Date	Outdoor	Barn Interior "A"	Barn Interior "B"	At Exhaust Fan	Tempered Fresh Air Inlet	Roofspace	
01/17/83	-28	18	17	--	--	--	--
01/21/83	-28	20	18	--	--	--	--
01/28/83	-14	20	20	10	--	- 8	80 *
02/04/83	-13	22	22	11	0	- 8	77
02/05/83	-23	20	20	11	- 4	-19	85
02/11/83	- 2	26	26	16	+ 9	--	81

* A ceiling mounted water training system was operating issuing a fine spray of water in almost all pens at the time of this check.

Grower Barn Temperature Recordings by Mr. Ron J. Rempel

TABLE 7

SUMMARY OF OPERATING CONDITIONS - REMPEL BARN

Date	Time	Temperature oC South End Therm. A	Temperature oC North End Therm. B
January 19	11:30 a.m.	20	8
January 23	5:15 p.m.	18	22
January 26	1:30 p.m.	20	20
January 30	4:00 p.m.	20	21
February 2	11:45 a.m.	22	21
February 7	7:30 a.m.	20	16
February 10	11:45 a.m.	21.5	21
February 13	5:00 p.m.	23	23
February 16	2:00 p.m.	26	24
February 20	9:00 a.m.	19	20
February 23	10:30 a.m.	24	23
February 27	1:30 p.m.	20	23
March 1	10:40 a.m.	17	17
March 5	9:00 a.m.	20	20
March 8	9:30 a.m.	21	19
March 13	9:00 a.m.	19	20
March 15	8:15 a.m.	19	18.5
March 19	12:00 noon	18	20
March 22	9:15 a.m.	19.5	20
March 26	2:20 p.m.	21	21
March 29	3:35 p.m.	23	24
April 2	10:30 a.m.	23	23

3.4.6 Economic Analysis

The cost of this installation is broken down as follows:

Robbco Heat Exchanger	$ 2,500
Shipping	50
Installation	350
Electric connection	75
Total	$ 2,915
Special exhaust duct	300
Special intake duct	150
Total	$ 3,425

The energy recovered during a normal Winnipeg area winter is estimated to be 43,699 BTU's with an average finisher barn temperature of 14^{o}C which, at 3¢ per kW.h, totals $1,311. This calculation is contained in Appendix "II".

It does not include electrical consumption by the fans of the heat exchanger which approximate a total of $100. This reduced the savings to $1,211.

For this net saving, the simple payback period for the installed exchanger itself is $2,975 - $1,211 = 2.5 years. For the exchanger plus special exhaust and intake ducting, the simple payback period is $3,425 - $1,211 = 2.8 years.

4.0 DISCUSSION

The use of an agricultural HRV is an efficient economic way to control the humidity level in animal barns and at the same time conserve energy.

For retrofit operations in Manitoba the simple payback period varies from 0.15 to 0.72 years for total investments from $2,680 to $3,645.

All of the farmers expressed satisfaction with the operation and maintenance aspects of the Robbco HRV.

5.0 CONCLUSIONS

This project is considered quite successful, having demonstrated substantial capital and operating savings. As well, the goal of a self cleaning heat exchanger has been realized.

6.0 RECOMMENDATIONS

That in cooperation with Agriculture Manitoba a seminar be developed illustrating the economics of heat recovery ventilators for animal barn operations.

APPENDIX I

REPORT ON 1984

FIELD TESTING OF

ROBBCO HEAT EXCHANGERS

by

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Technical Services & Training Branch
Manitoba Agriculture

March, 1984

REPORT ON 1984 FIELD EVALUATION OF ROBBCO HEAT EXCHANGERS

INTRODUCTION:

The Robbco heat exchanger is an air to air heat exchanger designed for use in recovering energy from exhaust ventilation air. It was designed for use in livestock buildings, where high dust and moisture conditions pose problems not normally present in many commercial and industrial applications. The exchanger consists of an outer shell that is approximately 1.1 m x 1.6 m and 29.9 m high within which a series of vertical polyethylene tubes are housed. Approximately 225 - 50 mm diameter tubes are spaced approximately 60 mm apart make up the exchanger core, providing a total heat transfer surface area of 78 m^2.

The thin walled (150 um) polyethylene tubes are inflated by positive pressure within the tubes and negative pressure within the outer housing. The waste air fan forces air through the exchanger core while the fresh air fan draws air from the attic space through the exchanger and then forces the air into the livestock building.

Waste air from the barn is forced to flow up through the bore of the tubes and is discharged out the top of the unit. Fresh air from the barn attic space is drawn into the top of the exchanger from one side and flows downward through the exchanger through the spaces surrounding the outer side of the vertical tubes. The pre-warmed fresh air is then delivered to the livestock barn. The two air streams are completely segregated through the unit with no cross-contamination between waste and fresh air.

Moisture from the waste air stream which condenses within the exhaust tubes drains down the tube walls to a collection pan from which a drain pipe conveys it to waste.

Though the unit is bulky it is intended for mounting outside the livestock building and its outer shell is suitably insulated (Figure 1).

Over the winter of 1983 - 84 four Robbco ventilation air heat exchangers were evaluated in swine facilities. Field tests were conducted to determine air handling capacity, energy recovery and thermal performance characteristics. The installations tested and test dates were as follows:

Rempel Farm, Blumenort, Manitoba

- Heat exchanger utilized to exhaust air from a finishing barn to preheat ingoing ventilation air for a grower barn housing smaller pigs.
- Test dates - February 8 & 9, 1984, February 13 & 14, 1984, March 8 & 9, 1984.

Riese Farm, Lockport, Manitoba

- Heat exchanger installed to provide exhaust ventilation and energy recovery for ventilation of a dry sow housing facility.
- Test dates - January 18 & 19, 1984, January 26 & 28, 1984.

Kehler Farm, Steinbach, Manitoba

- Heat exchanger installed to utilize waste air from dry sow and nursery areas to preheat intake air for ventilation of farrowing and nursery areas housing young pigs.
- Test dates - March 12 & 13, 1984.

Klippenstein Farm, Steinbach, Manitoba

- Heat exchanger installed to utilize all waste air from dry sow, farrowing and nursery areas to preheat intake air to ventilate farrowing and nursery areas housing young pigs.
- Test dates - March 18 & 19, 1984.

TEST METHODS:

The thermal performance of the exchangers was monitored over approximately 24 hours for each test period. Parameters monitored included waste air temperature and relative humidity before the exchanger, waste air temperature after the exchanger, ambient air temperature, fresh air temperature before the exchanger and fresh air temperature after the exchanger. Fresh air and waste air flow rates were measured at the beginning and end of each test period.

All temperatures were measured with type T thermocouples and a Fluke Model 1100B data logger. All data was recorded on cassette tape for subsequent computer analysis. Each temperature point was measured by three thermocouples whose values were averaged in data analysis. Temperature measurements were taken at approximately 30 minute intervals over each test period.

The relative humidity of the waste air before the exchanger was determined from its dry-bulb temperature and a wet-bulb temperature measured by a moist wick-covered thermocouple. A fan maintained a continuous flow of dust-filtered air over the wet-bulb thermocouple.

The techniques for measuring airflow varied from one site to another as dictated by the physical conditions of the installation. Airflow measurements were conducted by attaching duct sections in which velocity pressures were measured by 24 point pitot-static traverses. Measuring ducts were long enough to provide stable laminar flow profiles and of a suitable cross-section to provide air velocities in the range of 3 to 5 m/s. Airflow rates were calculated from the measured velocities and duct areas. All measuring ducts were installed prior to and removed at the end of each monitoring period.

In some cases the heat exchanger installation incorporated long duct sections which were suitable for measuring airflows and additional measurement ducts were not installed.

From the recorded temperature data and the airflow measurements the thermal performance of the exchangers was calculated. Fresh air heat gain was determined from the fresh air temperature rise across the heat exchanger and the fresh air flow rate. Exchanger efficiency was estimated by comparing the fresh air heat gain to the maximum energy gain based on enthalpy of the fresh air before the exchanger and the enthalpy of the waste air before the exchanger. The waste air enthalpy was determined from the temperature and relative humidity before the heat exchanger.

The waste air heat loss was also calculated to provide a cross-check of the test. However, the fresh air heat gain was assumed to be the more reliable indication of exchanger performance. The fresh air properties rely only upon air temperature and flow rate. Fresh air moisture content remains constant through the exchanger. On the other hand, waste air properties depend heavily upon air moisture content. Relative humidity measurements were imprecise and air moisture content after the exchanger was predicted but not monitored. In addition a method of accounting for the latent heat released by ice formation in the waste air passages was not available.

RESULTS AND DISCUSSION:

General observations of the exchangers and discussion with building operators at each site over the duration of the field testing period indicated that the units operated with very little supervision and no day to day maintenance. Other than a slight freezing problem which occurred during one test and was later corrected prior to a subsequent test no operational problems were found or identified. The manufacturer made slight adjustments over the testing period, but did not make changes which biased or prejudged the field performance testing and was most open and cooperative regarding operational details and changes.

The airflow rates measured for each of the heat exchangers tested is summarized in Table 1. Generally, airflows were consistent from the beginning to the end of each test. The airflows observed varied from location to location since each exchanger installation was slightly different. Adjustments to waste air pick-up ducts, fresh air delivery systems, and exchanger dampers made between some successive test runs account for airflow differences for the same exchanger on successive tests.

Direct leakage measurements were taken on the exchanger at the Riese operation. Waste air flow was measured before the exchanger and fresh air flow was measured before and after the exchanger. No measurable leakage from or into the fresh air stream could be detected. On several other occasions a smoke generator was used in the waste air pick-up duct to allow visual observation for leakage into or cross-contamination of the fresh air. At no time was any significant leakage apparent. From previous experience with laboratory prototype tests, leakage of from 2 to 5% of the airflow rate has been readily observed by this method.

The waste air exhaust at the Kehler and Klippenstein locations was noticeably lower and fresh air flows somewhat higher than at the other installations. The internal negative static pressure within the buildings became high at times when additional exhaust ventilation equipment operated. This condition decreased waste air flow and boosted fresh air flow. The installation of automatically controlled fresh air inlet dampers which bypassed the heat exchanger was recommended. In addition, since both of these installations utilized extensive pick-up ducting on the supply side of the waste air fan, fan output was reduced. It was recommended that larger waste air fans be retrofitted for these two sites to achieve waste air flows of 600 L/s.

The major change responsible for the dramatic increase in fresh air flow rates through the Rempel exchanger between the February and March tests was readjustment of air dampers on the unit and readjustment of other building ventilation equipment which had interferred with exchanger operation.

A sample of the data collected is presented in Table 2. The exchanger performance of each test run is summarized in Table 3. The energy recovery observed over each monitoring period is presented graphically in Figures 2, 3 and 4.

The two test runs of the exchanger at the Riese location displayed different thermal performance (Figure 2, Table 3). The exchanger performed more poorly over the first test run. The manufacturer attributed this to sub-optimal distribution of fresh air within the exchanger core. Minor inlet baffle modifications between the first and second run appeared to have resulted in improved exchanger performance.

The improved heat recovery of the Rempel unit over the March 8 and 9 test runs was the direct result of the higher airflow rates achieved (Figure 3, Table 1).

Over all testing periods the heat exchangers operated on a timer controlled defrost cycle in which the fresh air intake fan was shut down for a period of approximately 15 minutes every three hours. This cycle appeared to be sufficient to control ice buildup and maintain adequate exchanger performance.

Test run #1 provided a good assessment of potential freeze-up problems. Ambient temperatures dropped to -27°C during this test. Over the same period barn temperatures were 10 to 12°C. This barn air temperature is lower than would normally be encountered in most swine facilities but provided a good test of potential freeze-up since waste air heat flow was lower than would normally be expected. From Figure 5 it is apparent that through heat recovery dropped slightly over the periods between defrost events, each defrost cycle restored exchanger heat recovery. The exchanger could have continued to operate at these conditions for an indefinite period of time without complete freeze-up.

The energy recovered by an air to air heat exchanger increases as the temperature difference across the exchanger plate increases, if other conditions remain the same. Thus for the Robbco exchanger the heat recovery increases as the ambient temperature decreases for a constant barn temperature. In practice barn temperature seldom remains constant. Thus heat gain is related to the temperature difference between the barn temperature and ambient temperature. Figures 2, 3 and 4 graphically relate fresh air heat gain to the temperature difference between the waste air before the exchanger and the fresh air before the exchanger. The fresh air temperature before the exchanger is used instead of ambient temperature since the fresh air drawn from the building attic space is often several degrees warmer than ambient. This is due to solar gain on the building roof and heat loss into the attic through the building ceiling insulation.

The ratio of the fresh air heat gain to the temperature difference across the exchanger provides a relative measure of exchanger performance. The average ratio of fresh air heat gain to temperature difference across the heat exchangers varied from 0.26 to 0.39 over all test conditions (Table 3). Assuming that for all test conditions energy recovery will be zero where the difference between barn air temperature and the fresh air temperature before the exchanger is zero, this ratio represents the slope of the best fit line for the observed relation between fresh air heat gain and temperature difference across the exchanger (Figures 1, 2 and 3). For run #5 where this ratio is 0.39, had the exchanger operated with a barn air temperature of 20°C and an ambient temperature of -30°C it could be expected to achieve a peak energy recovery of approximately 20 kW.

In simple terms the energy flow in a counter flow heat exchanger can be described by:

$$Q = UA\ (\Delta T_{LM})$$

where

Q = energy flow rate (watts)

A = transfer surface area

U = overall heat transfer coefficient ($w/m^2\ ^oC$)

ΔT_{LM} = log mean temperature difference across the exchanger (^oC)

and

$$\Delta T_{LM} = \frac{T_1 - T_2}{Ln\ (T_1/T_2)}$$

T_1 = temperature difference across the exchanger surfaces at one end (^oC)

T_2 = temperature difference across the exchanger surfaces at the other end.

Air velocity over the exchanger core surfaces is known to affect the heat transfer coefficient. Because of the shell and tube design of the Robbco exchanger it is difficult to predict the air velocity over the outer surface of the exchanger tube surfaces. From tests conducted on a single plate exchanger utilizing similar exchanger surface material[1], it was found that the surface heat transfer coefficient increased consistently with increasing air velocity over the exchange surface over a range of 1 to 4 m/s. A similar relationship is anticipated for the Robbco exchanger.

In the absence of a precise evaluation of internal air velocity characteristics, the approximate effect of air velocity can be demonstrated by comparing the apparent heat transfer coefficients at different air flow rates. As the total exchanger air flow (sum of waste and fresh air) increases the average velocity over the tube surfaces would be expected to increase. A comparison of the total exchanger airflow to the apparent overall heat transfer coefficient (Table 4) suggests that an exchanger core velocity effect exists. Though test run #1 is a significant variation, the previously discussed internal air distribution problem could logically have accounted for the sub-normal performance of the exchanger over this test run. A more thorough investigation of the internal air velocity effects on exchanger performance is warranted. It appears that there may be potential to increase exchanger efficiency through optimizing airflow rates through the core and/or considering internal design changes which optimize air velocities over the tube walls.

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1) Field Evaluation of a Single Plate Air to Air Heat Exchanger for Livestock Buildings; D. Hodgkinson, D. Small, Canadian Society of Agricultural Engineers; CSAE 84-403, 1984.

All heat exchangers operated continuously from start-up over the duration of the 83 - 84 heating season. Dust accumulations were not cleaned out of the units at any point. The only washing of exchanger surfaces was that which occurred naturally as a result of condensation and drainage from within the exhaust air tubes. If a film of dust and grime continued to accumulate in the exchanger passages with time a reduction of the apparent overall heat transfer coefficient would have been evident.

Since the heat transfer coefficients were similar for test runs at similar airflow rates irrespective of test dates or test units it was concluded that the units were not subject to ongoing cumulative fouling (Table 4).

The barn which supplied waste air to the Rempel exchanger provided the most severe dust loads of all units tested. Comparison of the apparent heat transfer coefficients observed over test runs #3 and #4 is presented in Figure 6. For both tests the exchanger operated over similar conditions and at similar airflow rates. Over these two successive runs, encompassing approximately 200 hours of uninterrupted operation, a decrease in the apparent heat transfer coefficient was not detected. It was concluded that the normal cleaning of the exchanger surfaces resulting by moisture condensation and drainage and ice formation and ice crystal clearance from the tube walls was sufficient to control surface fouling and maintain consistent exchanger performance.

Exchanger efficiency is a measure of the proportion of the total heat (sensible plus latent heat) contained in the waste air stream that is recaptured and transferred into the fresh air stream. Air enthalpy is a measure of the total heat contained in a unit mass of air and is determined from standard psychrometric air properties and air temperature and humidity. Considering the waste air stream of a heat exchanger, sensible heat is the heat released by cooling the air mass. Latent heat is the heat released by moisture condensing out of the waste air mass.

The performance of the humidity monitoring equipment used in the field tests was erratic. Equipment failures occurred part way through two tests. Dust overloading of the filter system and dust contamination of the wick covered thermocouple contributed to gradual loss of accuracy over the test periods. However some of the data collected could be corroborated by manual humidity measurements taken while technicians were on the site and allowed estimation of air enthalpies. Total efficiency was calculated as follows[1]:

$$e = \frac{\dot{M}_{FA}\, h_{FA}}{\dot{M}_{min}\, h_{max}}$$

where

$\dot{M}_{FA}$ = mass flow rate of fresh air (kg/s)

$\dot{M}_{min}$ = minimum mass airflow rate (fresh air or waste air)

1) ASHRAE Handbook "Air to Air Heat Recovery Equipment", 1979.

h_{FA} = enthalpy change of (kj/kg) fresh air

h_{max} = enthalpy difference between barn air and fresh air before exchanger.

Exchanger efficiency, based on air enthalpies, ranged from 20 to 30% over all tests except run #5. For the March 8 and 9 test of the Rempel exchanger (run #5) the exchanger efficiency ranged from 30 to 35%. The higher efficiency achieved for this run is the result of the exchanger operating at higher airflow rates for both the fresh and waste air sides of the exchanger. The higher air velocity over the tubes in this test run resulted in a higher heat transfer rate and higher operational efficiency.

Sensible effectiveness was also calculated according to the method outlined by PAMI[2] for livestock building heat exchangers as follows:

$$R_{HR} = \frac{\dot{M}_{FA}\, C_p\, (t_2 - t_1)\, (1 - f)}{\dot{M}_{WA}\, C_p\, (t_3 - t_1)}$$

where

R_{HR} = PAMI Heat Recovery Ratio

$\dot{M}_{FA}$ = fresh air mass flowrate (kg/s)

$\dot{M}_{WA}$ = waste airflow rate (Kg/s)

C_p = specific heat of air (Kj/kg ^{o}C)

t_1 = fresh air temperature before exchanger ^{o}C

t_2 = fresh air temperature after exchanger ^{o}C

t_3 = waste air temperature before exchanger ^{o}C

f = fraction of time exchanger is operating in defrost mode.

The PAMI Heat Recovery Ratio is a measure of the proportion of the sensible heat contained in waste air that is recaptured and transferred into the fresh air stream. Since the waste air stream also contains a significant proportion of latent heat it is possible for an exchanger to achieve heat recovery ratios in excess of 100%.

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2) Prairie Agricultural Machinery Institute, Test Procedures, November, 1983.

Values for the PAMI heat recovery ratio observed in the Robbco tests is provided in Table 2. These values were determined only to provide comparative information compatable with other heat exchanger performance data published. Over the range of operating conditions tested the Robbco exchanger achieved heat recovery ratios varying from 32 to 64%. In laboratory tests of two other types of commercially available heat exchangers for livestock buildings conducted by PAMI, heat recovery ratios varying from 24 to 72% were observed for one unit and 39 to 50% for the other. However, sensible effectiveness, of which the heat recovery ratio is a measure, is an extremely poor term by which to compare exchanger performance in livestock facilities. Approximately 1/2 the heat recovered by a typical heat exchanger operating in a livestock building is the result of the recapture of latent heat released from the waste air stream by condensation and ice formation. Thus an inefficient exchanger operating in a very humid environment could appear to outperform a more efficient unit operating at similar temperatures in a dry environment. Thus exchanger performance should be documented in terms of efficiency determinations based on air enthalpy to allow valid comparison between different field tests and between field and laboratory tests.

The long term durability of the exchanger or its components was not addressed. The internal components and overall fabrication of the unit should pose no concern. The fragility of the outer styrofoam shell may be a concern to some livestock producers and in some applications.

CONCLUSIONS AND RECOMMENDATIONS:

1. All four Robbco heat exchangers evaluated operated with minimum supervision and no routine maintenance or servicing over the total testing period. No major operational problems were observed by those conducting field tests or reported by cooperating livestock producers or their staff.

2. The routine defrost cycle in which the fresh air intake fan was shut down for 15 minutes at three hour intervals prevented exchanger freeze-up over all test conditions down to an ambient temperature of -27°C.

3. The normal drainage of condensed moisture and clearance of ice crystals sloughed off the exchanger tubes during operation and defrosting was sufficient to control dust and grime accumulation. Ongoing build-up and increasing surface fouling did not occur. Additional cleaning by the operators was not provided or needed.

4. On test the Robbco exchanger developed a peak energy recovery rate ranging from 6 to 14 kW over all tests. The energy recovery rate was limited in some tests by the sub-optimal air flow rates achieved through the unit. In these cases altering the installation or exchanger fans to attain higher airflows could bring all units up to the maximum performance observed. In tests where design airflow rates of 500 to 600 L/s for both the fresh and waste air streams were achieved maximum energy recovery was limited only by the ambient temperatures encountered over the test periods.

5. For installations in which airflows in the range of 500 to 600 L/s can be provided, the Robbco exchanger can be expected to maintain a heat recovery rate of from 0.33 to 0.38 kW per °C difference between the barn air temperature and the temperature of the fresh air before the heat exchanger.

6. Waste airflows of 600 L/s and fresh airflows of 550 L/s can be achieved through the exchanger as currently designed and equipped. For a barn operating condition of 20°C and 70 to 80% RH the exchanger can develop a peak energy recovery rate of approximately 20 kW at an ambient temperature of -30°C.

7. Care must be taken in planning the exchanger installation so as not to unduly restrict the airflow through the exchanger. For installations where a large amount of peripheral air supply and delivery ducting is needed, consideration should be given to providing larger fans if maximum energy recovery capacity is desired. Maximum energy recovery capacity will be achieved only if design airflow rates are maintained.

8. Total heat (enthalpy) efficiency of the Robbco exchangers tested ranged from 20 to 35% depending on the installation and operating conditions. At airflow rates of 600 L/s waste and and 550 L/s fresh air and peak recovery rate of 20 kW, the exchanger can be expected to operate at total heat efficiency of 35%.

9. Sensible effectiveness as determined by the PAMI heat recovery ratio ranged from 32 to 64% over all test conditions. This performance is comparable to other commercial exchangers currently available.

10. Additional evaluation and development work aimed at optimizing internal air passage velocities and overall airflow rates warrants consideration by the manufacturer.

The thermal performance and operational characteristics of the Robbco exchanger are satisfactory for livestock building ventilation applications. Its thermal performance is comparable to other available equipment. The low maintenance and servicing requirements will be very attractive to livestock producers. The elimination of exchanger core cleaning achieved by the Robbco design is unique among currently available exchangers for livestock housing applications.

ACKNOWLEDGEMENTS:

Appreciation is extended to R. Robbins and the farm cooperators for the access provided to the test units. Field monitoring costs were supported in part under the Agro-Man Project #104-13 Building Ventilation.

D. Hodkginson, P. Eng.
Agricultural Engineer
Manitoba Agriculture

DH/sd

March, 1985

TABLE 1

AIRFLOWS (L/s)

LOCATION	DATE	RUN	INTAKE AIRFLOW START OF TEST	INTAKE AIRFLOW END OF TEST	EXHAUST AIRFLOW START OF TEST	EXHAUST AIRFLOW END OF TEST
Riese	Jan. 18&19/84	1	420	390	635	650
Reise	Jan. 26&2S/84	2	434	435	620	622
Rempel	Feb. 8 & 9/84	3	420	450	490	320
Rempel	Feb. 13&14/84	4	435	438	500	493
Rempel	Mar. 8 & 9/84	5	560	550	580	580
Kehler	Mar. 12&13/84	6	530	580	406	403
Klippen-stein	Mar. 19&20/84	7	560	560	490	470

RIESE-KORCO HEAT EXCHANGER
TESTED JAN. 26-27 1984
REVUN APRIL 2 1985

TABLE 2 SAMPLE DATA
RIESE-EXCHANGER

	AIRFLOW L/s
FRESH AIR BEFORE EXCHANGER•)	435
FRESH AIR AFTER EXCHANGER•)	n/a
FRESH AIR LEAKAGE•)	n/a
WASTE AIR BEFORE EXCHANGER•)	420
WASTE AIR AFTER EXCHANGER•)	n/a
WASTE AIR LEAKAGE•)	n/a
AMBIENT RELATIVE HUMIDITY•)	80 %

TIME	INT	AMB	TFAB	RMS	TFAA	RMS	HUFA	AMB	THUFA	AS/TS	TMAB	RMS	RHMAB	TAAA	RMS	RHMAA	COND	HLMA	MS/ML	MAS	EFF	SYEFF	SENEF	PHOR
17.4721	.0	n/a	-11.3	.6	3.1	.4	9.7	n/a	9.7	n/a	16.6	.2	.83	9.1	1.0	1.00	4.8	10.8	.90	29.4	.33	.33	.39	.46
17.4778	.3	n/a	-11.4	.6	3.1	.4	9.7	n/a	9.7	n/a	16.7	.1	.82	9.2	1.1	1.00	4.5	10.5	.93	29.4	.33	.33	.39	.46
17.4834	.3	n/a	-11.3	.4	3.0	.4	9.6	n/a	9.6	n/a	16.8	.2	.82	9.2	1.1	1.00	4.5	10.6	.91	29.4	.33	.33	.38	.46
18.4839	60.0	n/a	-12.1	.4	4.4	.2	9.8	n/a	9.8	n/a	16.4	.2	.83	8.7	1.6	1.00	4.8	10.9	.89	29.7	.33	.33	.38	.46
18.9839	30.0	n/a	-12.8	.3	3.5	.3	9.7	n/a	9.7	n/a	16.0	.3	.82	8.0	1.9	1.00	4.8	10.9	.89	29.7	.33	.33	.37	.45
19.4839	30.0	n/a	-13.4	.3	3.0	.2	9.8	n/a	9.8	n/a	15.3	.1	.82	7.3	1.9	1.00	5.0	10.8	.90	29.1	.33	.33	.37	.45
19.9839	30.0	n/a	-14.0	.8	2.6	.3	9.9	n/a	9.9	n/a	12.3	.2	.80	7.2	2.1	1.00	4.9	10.9	.91	29.3	.34	.34	.37	.45
20.4839	30.0	n/a	-14.3	.4	2.3	.2	9.9	n/a	9.9	n/a	13.0	.1	.79	7.0	2.1	1.00	4.9	10.8	.91	29.2	.34	.34	.37	.45
21.4839	60.0	n/a	-14.5	.2	1.7	.3	9.7	n/a	9.7	n/a	14.4	.3	.81	6.0	2.0	1.00	5.0	10.9	.88	28.2	.34	.34	.36	.44
21.9839	30.0	n/a	-15.6	.9	.9	.3	9.9	n/a	9.9	n/a	14.0	.3	.82	5.5	2.2	1.00	5.4	11.3	.87	28.9	.34	.34	.36	.44
22.4839	30.0	n/a	-16.1	.1	.2	.3	9.8	n/a	9.8	n/a	13.6	.3	.81	5.1	2.1	1.00	5.2	11.0	.89	28.5	.34	.34	.35	.43
22.9839	30.0	n/a	-15.1	.3	.2	.2	9.8	n/a	9.8	n/a	14.0	.3	.78	5.2	2.1	1.00	4.9	11.0	.89	28.6	.34	.34	.34	.43
23.4839	30.0	n/a	-16.6	.4	-.1	.2	9.9	n/a	9.9	n/a	13.7	.2	.80	4.9	2.0	1.00	5.2	11.2	.89	28.8	.34	.34	.34	.43
.4839	60.0	n/a	-17.0	.3	-.2	.2	10.1	n/a	10.1	n/a	13.2	.2	.80	4.3	2.6	1.00	5.4	11.3	.90	28.5	.34	.34	.34	.43
.9839	30.0	n/a	-17.8	.3	-.7	.2	10.3	n/a	10.3	n/a	13.1	.2	.78	4.0	2.6	1.00	5.3	11.3	.92	28.8	.34	.34	.34	.44
1.4839	30.0	n/a	-17.7	.2	-1.1	.3	10.0	n/a	10.0	n/a	12.7	.3	.79	3.8	2.2	1.00	5.3	11.1	.91	28.3	.33	.33	.33	.43
1.9839	30.0	n/a	-18.1	.4	-1.5	.3	10.1	n/a	10.1	n/a	12.3	.2	.79	3.4	2.1	1.00	5.3	11.1	.90	28.2	.34	.34	.33	.43
2.4839	30.0	n/a	-18.4	.1	-1.9	.2	10.1	n/a	10.1	n/a	12.4	.0	.78	3.3	1.7	1.00	5.4	11.2	.91	28.5	.34	.34	.34	.43
3.4839	60.0	n/a	-18.1	.2	-.7	.3	10.3	n/a	10.3	n/a	13.1	.6	.78	4.0	2.1	1.00	5.3	11.3	.93	29.1	.34	.34	.34	.44
3.9839	30.0	n/a	-18.2	.4	-1.4	.2	10.2	n/a	10.2	n/a	12.2	.3	.79	3.3	2.2	1.00	5.3	11.2	.91	28.2	.34	.34	.33	.44
4.4839	30.0	n/a	-18.9	.4	-1.8	.3	10.4	n/a	10.4	n/a	12.4	.2	.77	3.1	2.2	1.00	5.4	11.3	.92	28.6	.34	.34	.33	.43
4.9839	30.0	n/a	-18.9	.4	-2.1	.3	10.2	n/a	10.2	n/a	12.6	.9	.76	3.1	1.9	1.00	5.3	11.3	.90	28.7	.34	.34	.33	.42
5.4839	30.0	n/a	-18.8	.4	-2.2	.3	10.1	n/a	10.1	n/a	12.0	.4	.77	3.0	1.6	1.00	5.1	10.8	.93	28.1	.34	.34	.34	.43
6.4839	60.0	n/a	-18.6	.2	-1.6	.3	10.3	n/a	10.3	n/a	11.9	.3	.78	2.9	2.6	1.00	5.4	11.1	.93	28.0	.37	.37	.36	.44
6.9839	30.0	n/a	-18.6	.2	-1.9	.3	10.1	n/a	10.1	n/a	12.2	.4	.76	2.7	2.5	1.00	5.2	11.2	.90	27.9	.36	.36	.34	.43
7.4839	30.0	n/a	-18.3	.1	-1.9	.2	9.9	n/a	9.9	n/a	11.8	.6	.75	2.9	2.1	1.00	4.7	10.4	.94	27.2	.37	.37	.34	.43
7.9839	30.0	n/a	-18.1	.2	-1.6	.3	10.0	n/a	10.0	n/a	12.4	.1	.75	2.3	1.8	1.00	4.8	10.6	.94	27.7	.36	.36	.34	.43
8.4839	30.0	n/a	-17.7	.1	-1.7	.2	9.7	n/a	9.7	n/a	11.8	.2	.77	2.8	1.7	1.00	4.9	10.5	.92	26.9	.36	.36	.34	.43
8.9839	60.0	n/a	-17.5	.1	-.8	.3	9.8	n/a	9.8	n/a	12.2	.6	.78	2.7	2.1	1.00	4.7	10.2	.95	27.0	.36	.36	.33	.44
9.4839	30.0	n/a	-17.6	.1	-.8	.3	9.8	n/a	9.8	n/a	12.2	.6	.78	2.7	2.1	1.00	4.8	10.2	.94	27.1	.37	.37	.34	.44
10.4839	30.0	n/a	-16.4	.4	-.3	.2	9.7	n/a	9.7	n/a	12.1	.2	.79	4.0	2.2	1.00	4.8	9.7	1.00	28.6	.36	.36	.36	.44
10.9839	30.0	n/a	-16.2	.2	-.2	.2	9.6	n/a	9.6	n/a	12.1	.2	.79	4.0	2.2	1.00	4.8	9.7	.99	28.5	.36	.36	.36	.44
11.4839	30.0	n/a	-16.4	.1	.4	.2	10.1	n/a	10.1	n/a	12.1	.2	.81	4.0	2.2	1.00	4.8	9.7	1.04	27.8	.36	.36	.37	.45

TABLE 3 ROBBCO EXCHANGER PERFORMANCE SUMMARY

PLACE	DATE	RUN	AIRFLOWS (L/s) INTAKE	AIRFLOWS (L/s) EXHAUST	TEMP. DIFF. (°C) MAX	TEMP. DIFF. (°C) MIN	TEMP. DIFF. (°C) AVG.	HEAT GAIN FRESH AIR (kW) MAX	HEAT GAIN FRESH AIR (kW) MIN	HEAT GAIN FRESH AIR (kW) AVG.	PARI HEAT RECOVERY RATIO MAX	PARI HEAT RECOVERY RATIO MIN	PARI HEAT RECOVERY RATIO AVG.	HCFA/TDBA AVG. (kW/°C)
Hank Reise	18-19:01:84	1	485	640	34.5	32.6	34.4	10.10	8.7	9.19	0.36	0.32	0.34	.3672
Reise	26-28:01:84	2	435	620	31.3	27.9	29.8	10.50	9.60	9.95	0.46	0.42	0.44	.3344
Rempel	8-9:02:84	3	435	505	26.6	19.5	21.0	7.8	5.7	6.6	0.5	0.4	0.5	.2870
Non Rempel	13-14:02:84	4	435	495	16.8	11.2	13.8	5.2	3.0	3.9	0.6	0.4	0.5	.2826
Rempel	8-9:03:84	5	555	580	36.8	18.7	29.2	14.0	7.90	11.25	0.62	0.46	0.54	.3875
Kehler	13:03:84	6	550	405	21.9	13.8	18.9	7.0	4.10	5.89	0.64	0.58	0.61	.3115
Klippenstein	19:03:84	7	560	480	17.1	11.4	15.7	5.8	3.4	5.23	0.38	0.31	0.33	.3327

NOTE:

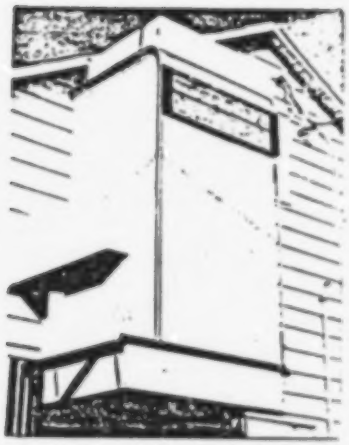
TEMP. DIFF. = Room air temperature minus temperature of fresh air before exchanger.

HCFA/TDBA = Heat gain/temperature difference

TABLE 4 APPARENT HEAT TRANSFER COEFFICIENT

RUN	TEST UNIT	TOTAL EXCHANGER AIRFLOW (INTAKE & EXHAUST) (L/s)	APPARENT OVERALL HEAT TRANSFER COEFFICIENT ($w/m^2\ °C$)
5	Rempel Mar. 8-9	1135	8.0
2	Reise Jan. 26-28	1055	7.5
1	Reise Jan. 18-19	1045	5.4
7	Klippenstein Mar. 19-20	1040	7.3
6	Kehler Mar. 12-13	955	6.5
3	Rempel Feb. 8-9	940	6.0
4	Rempel Feb. 13-14	930	6.1

FIGURE 1 EXCHANGER INSTALLATION AT RIESE FARM
AND SCHEMATIC OF EXCHANGER



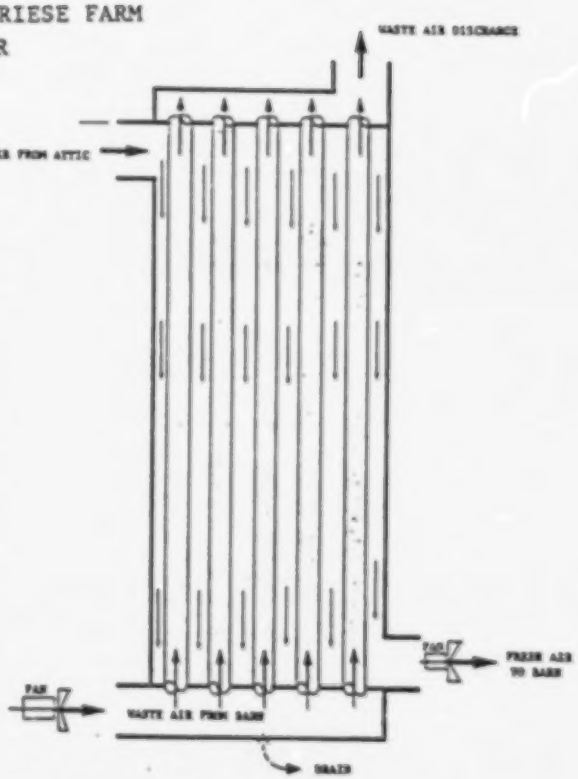


FIGURE 2 FRESH AIR HEAT GAIN
RIESE EXCHANGER

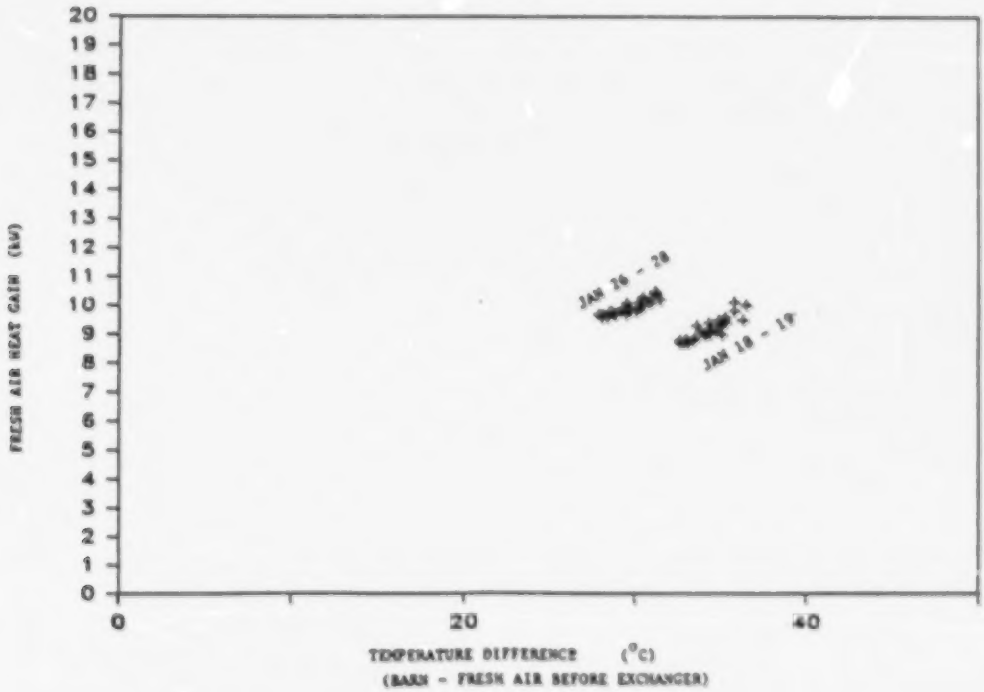


FIGURE 3 FRESH AIR HEAT GAIN
REMPEL EXCHANGER

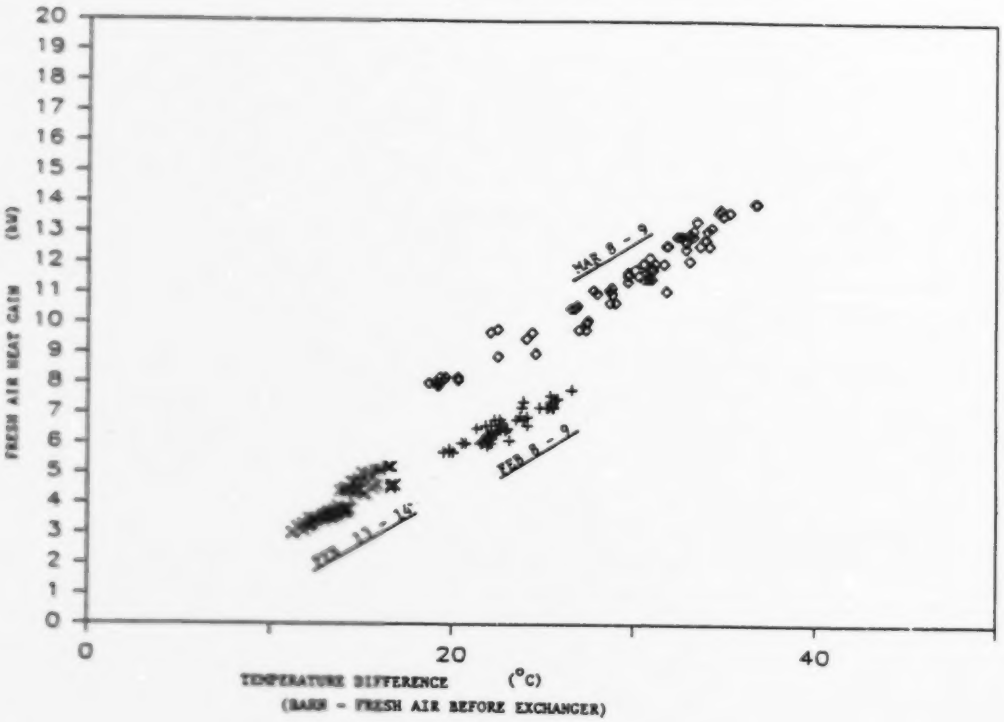


FIGURE 4 FRESH AIR HEAT GAIN
KEHLER & KLIPPENSTEIN EXCHANGER

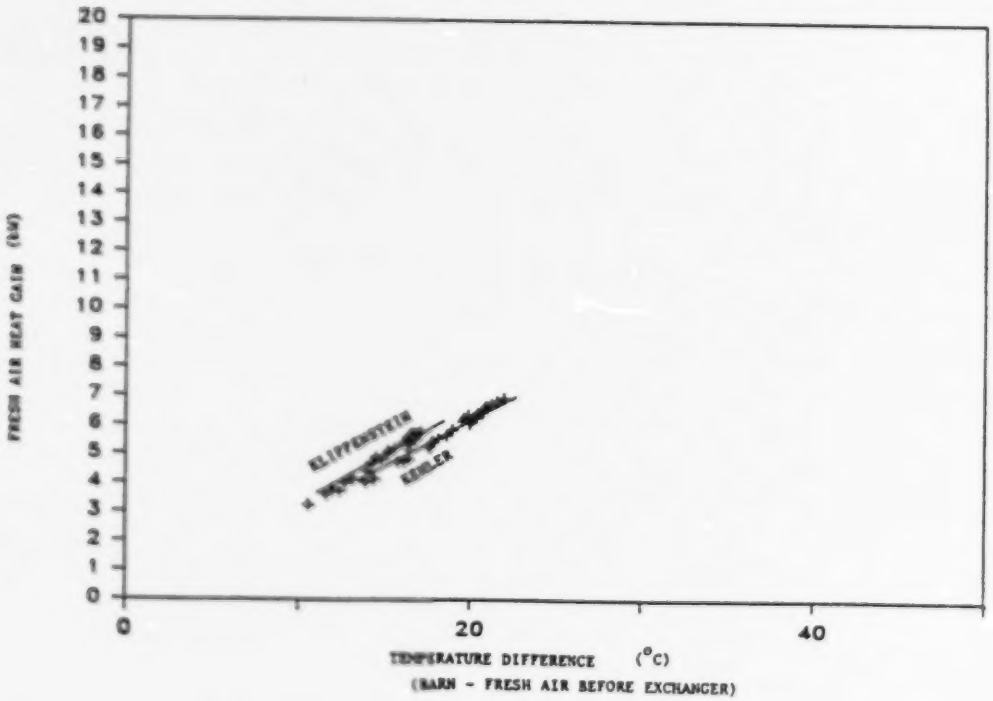


FIGURE 5 HEAT GAIN vs ELAPSED TIME
RIESE EXCHANGER JAN 18 - 19

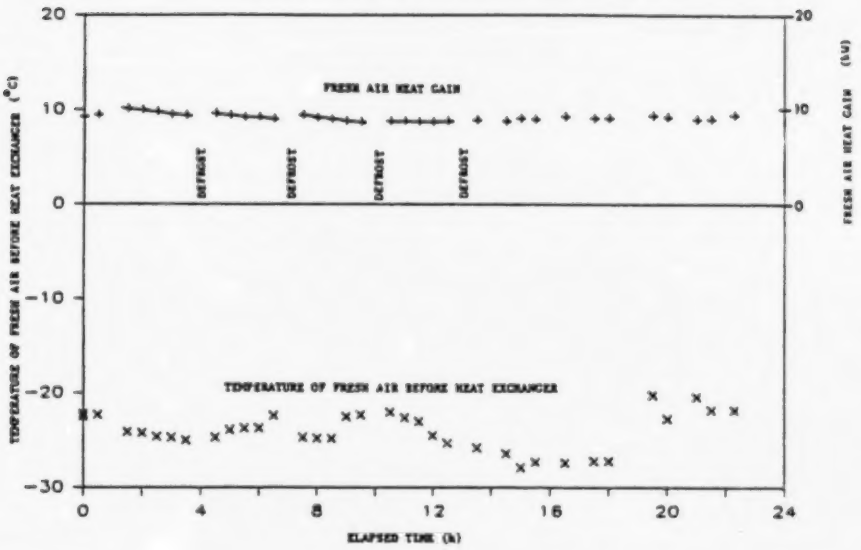
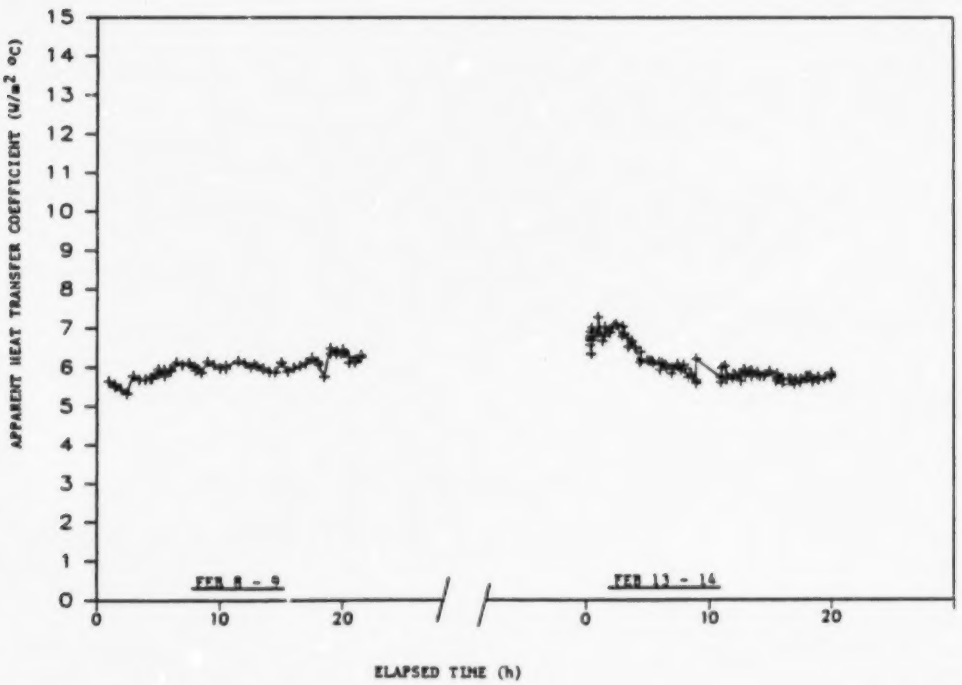


FIGURE 6 APPARENT HEAT TRANSFER COEFFICIENT
vs ELAPSED TIME REMPEL EXCHANGER



APPENDIX II

Determination of Energy Savings Effected by Robbco Model A1 Heat Exchanger in the Winnipeg Area

Method:

The peak capacity of 20 kW, as determined by tests conducted by M.D.A., is prorated according to the normal winter mean temperature for each month. This prorated capacity is multiplied by the number of days in a month times 24 hours to obtain the number of kW.h of heat transferred. This calculation is totalled for the period of November 1 to April 15 inclusive. (One operator used the Robbco heat exchanger during May of 1984 utilizing it for overnight heating. May was exceptionally cool in 1984).

In this installation the readings recorded by the owner as detailed in Appendix III would erroneously suggest an energy saving of $2,646 because the average temperature within the grower barn was 21°C. However, the exchanger was supplied with exhaust air from the finisher barn at a much lower average temperature of 13°C - 16°C. On the basis of an average temperature of 14°C, the following calculations provide a lesser amount of saving.

The peak capacity of 20 kW., as determined by M.D.A., is based on a temperature difference of 50°C between indoors and outdoors. when the difference is less than 50°C, the "Factor" below is less than 1.0.

Month	Mean Temp.* °C	Ins. to Outs. Temp. Diff.	Factor	Factor x 20 = kW. Avge. H.X. Capacity	kW.h ** Saved
January	-33	47	.94	18.8	13,987
February	-16	30	.60	12.0	8,064
March	- 8	22	.44	8.8	6,547
April	+ 3	11	.22	4.4	1,584
November	- 4	18	.36	7.2	5,184
December	-14	28	.56	11.2	8,333
				Total	43,699

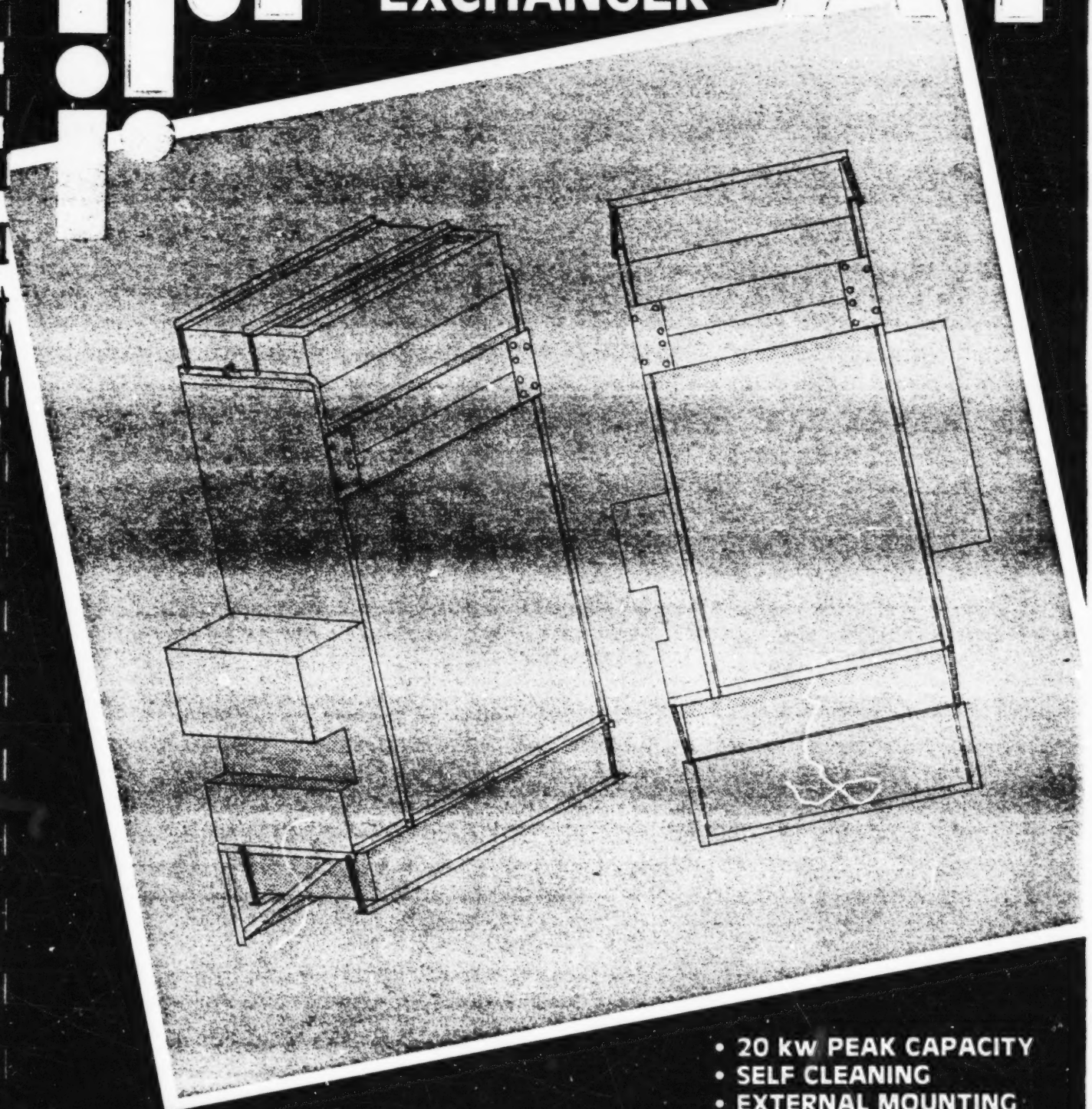
* Based on Winnipeg area

** = kW.h average Heat Exchanger Capacity x 24 hours x days in month

Annual saving at 3¢ per kW.h = $1,311.

APPENDIX III

ROBBCO Livestock HEAT EXCHANGER A1



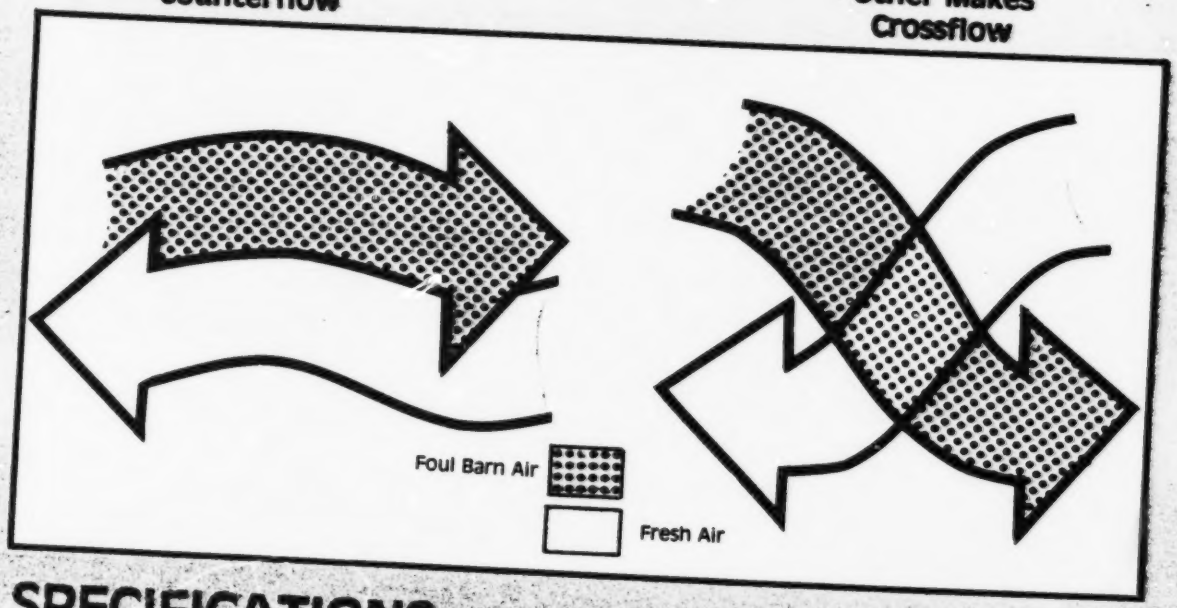
- 20 kw PEAK CAPACITY
- SELF CLEANING
- EXTERNAL MOUNTING
- BARN TO BARN HEAT TRANSFER

THE ROBBCO HEAT EXCHANGER

Uses a counterflow design for greater heat transfer efficiency.

Robbco Design
Counterflow

Other Makes
Crossflow



SPECIFICATIONS:

Recommended for up to 600 finisher pig barn or equivalent.

Housing Dimensions —

Width — Variable 1650 - 2083 mm (5'5"-6'10")

Depth — 1100 mm (3'7")

Height — 2896 mm (9'6")

Insulation Value — R 10

Fan Selection — Tunnel type, same size for exhaust and intake.

Sizes — 14" or 16" for engineered ducted systems.

Weight — Overall 136 kg (300 lbs.) Housing only — 48 kg (105 lbs.)

Mounting — External wall mounting of housing. Fans mounted on interior wall surface over integral ductwork.

Defrost timer — Adjustable, separately mounted.

AN EXAMPLE OF A ROBBCO A1 SYSTEM

Hog Finishing Barn

Dimensions: 11 x 45.7 m = 502.7 m² (36' x 150' = 5400 ft.²)

New Construction: R20 insulation including fans with polyduct under air inlets blending barn air with incoming fresh air.

Animals: 600 feeders — 54.4 - 90.7 kg. (120-200 lbs.)

Recommendation: Install one Robbco Model A1 and operate one 18"-24" wall fan on thermostat so as to hold desired temperature in barn. Operate more fans as outdoor temperature rises.

As a matter of interest, animal heat generation in this "Example" is 764 B.T.U. per hour per m² (71 B.T.U. per hour per ft.²). This is almost double the animal heat generation that is available in the "ACTUAL INSTALLATION" for the "Dry Sow - Finisher" barn (see next page). With this amount of heat, direct exhaust by wall fans along with the Robbco A1 will sustain desired barn temperatures.

ADVANTAGES

Heating Capacity

Under actual working conditions, the Robbco heat exchanger sustained 20KW heating capacity. Several Robbco heat exchangers have been extensively field tested after months of continuous unattended operation.

You can save both capital and operating costs by including the Robbco heat exchanger in your plans when designing a new Farrowing-Nursery barn or renovating your existing barn. The Robbco heat exchanger will save you as much as $2500 by allowing you to reduce your electrical service capacity and by eliminating the need for 20KW's of supplementary heating.

Exclusive Self Cleaning Feature

The unique design of the Robbco heat exchanger uses normal build up of ice and condensation to automatically clean the heat exchanger surfaces. You will not have to clean the heat exchanger from fall start up to spring shut down. The Robbco heat exchanger will provide you with continuous trouble free operation at peak capacity.

External Mounting

The Robbco heat exchanger is constructed of lightweight material. Our design allows for external mounting directly on your barn wall. This feature maximizes barn space utilization for livestock operations.

Exclusive Barn To Barn Heat Transfer

Simply by adding ductwork, air normally discharged directly to outdoors from your finisher barn can be exhausted through your Robbco heat exchanger. Heat will then be transferred to fresh air which is drawn from the attic of the grower barn and delivered into the grower area. The installation of a Robbco heat exchanger will eliminate the need for supplementary heat in the grower barn.

TESTIMONIALS

Abe Kehler

I recently installed the Robbco heat exchanger in my new Farrowing-Nursery barn and I have already realized savings which will quickly return my investment.

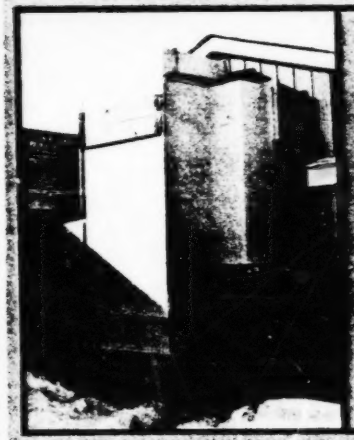
Ron Rempel

I am pleased with the Robbco heat exchanger. It has greatly improved the environment in our grower barn without taking any of my time for cleaning.

ACTUAL INSTALLATIONS

Data below based on normal winter in area adjacent to Winnipeg, Canada.

Figures for "Energy Saved" may be increased by an average of 10% to account for heat recovery by roofspace air drawn into the Robco heat exchanger.



Occupancy/Area

40 Sow Farrowing-Nursery Barn — 468.5 m² (5040 ft.²)

Construction

Walls	Ceiling
R20	R20

Supplemental Heat

20 K.W. peak capacity Robbco heat exchanger plus 2-5 K.W. heaters and heat lamps as req'd.

Estimated Seasonal Heat Transfer by Heat Exchanger = Energy Saved

44,500 K.W.H. @ 3.0¢ per K.W.H. = $1335. Exhaust air at average of 18°C (65°F).

• Equipped with one Robbco A1

Occupancy/Area

Grower barn — 615 of 27 kg. (60 lbs.) grower pigs. 337.5 m² (3633 ft.²)

Construction

Walls	Ceiling
R20	R16

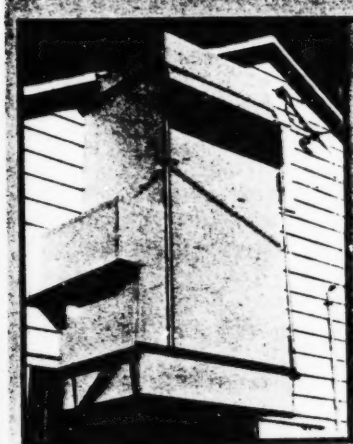
Supplemental Heat

20 K.W. peak capacity Robbco heat exchanger only.

Estimated Seasonal Heat Transfer by Heat Exchanger = Energy Saved

37,000 K.W.H. @ 3.0¢ per K.W.H. = $1110. Average finisher barn temp. of 13°C (55°F). Air of finisher barn exhausted through heat exchanger.

• Equipped with one Robbco A1 — Barn to Barn heat transfer



Occupancy/Area

Dry Sow-Finisher barn 403.75 m² (4346 ft.²)

Construction

Walls	Ceiling
R10	R16

Supplemental Heat

20 K.W. peak capacity Robbco heat exchanger only.

Estimated Seasonal Heat Transfer by Heat Exchanger = Energy Saved

40,500 K.W.H. @ 3.0¢ per K.W.H. = $1215. Barn operated at average temperature of 16°C (60°F).

• Equipped with one Robbco A1